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Containment Event Analysis for Postulated Severe Accidents: Surry Power Station, Unit 1

A. S. Benjamin, V. L. Behr, D. M. Kunsman, W. B. Murfin

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Sandia National Laboratories
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by

A. S. BENJAMIN
V. L. BEHR
D. M. KUNSMAN
W. B. MURFIN*

Printed: February 1987

Sandia National Laboratories
Albuquerque, New Mexico 87185
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*Technadyne Engineering Consultants, Inc.,
Albuquerque, New Mexico

PREFACE

Because of the time constraints imposed on this work to meet the Nuclear Regulatory Commission's schedule for publication of NUREG-1150, this draft report has not yet received the full level of peer and management review customarily accorded to reports issued by Sandia National Laboratories. The reviews will be completed and corrections made, if necessary, prior to final publication.

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REQUEST FOR COMMENT

This report, NUREG/CR-4700, "Containment Event Analysis for Postulated Severe Accidents," was prepared for the U.S. Nuclear Regulatory Commission by the Sandia National Laboratories and its subcontractors.

The methods and results set forth in this report are being used by the NRC to support the development of the Reactor Risk Reference Document (NUREG-1150) and will be used in areas of broad public interest such as probabilistic risk analyses, emergency response planning, siting, NRC safety goal applications, and cost/risk/benefit analyses--indeed, wherever risks to public health need to be considered in regulatory applications. Thus, it is considered imperative that an opportunity for public comment on the results as presented in the report be provided. Comments should be sent to the U. S. Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Joseph Murphy, Division of Reactor System Safety. These comments will be most useful to the staff if they are received by June 1, 1987.

Of particular interest to us is the receipt of comments on the methodology, and results, related to uncertainty analysis. One criticism voiced with respect to the Reactor Safety Study was its lack of an uncertainty analysis. We have included an uncertainty analysis, but we are sure that its nature will be the subject of lively debate. We welcome this, and solicit constructive advice and criticism.

The NRC hereby expresses its great appreciation to all participants in this study for their considerable efforts, as well as to all who will take the time and effort to provide it with comments on this report.

D. F. Ross, Deputy Director
Office of Nuclear Regulatory Research

ABSTRACT

A study has been performed as part of the Severe Accident Risk Reduction Program (SARRP) to investigate the response of a particular pressurized water reactor with a subatmospheric containment (Surry Unit 1) to postulated severe accidents. A detailed containment event tree for the Surry plant has been devised to describe the various possible accident pathways that can lead to radioactive releases from containment. Data and analyses from a large number of NRC and industry-sponsored programs have been reviewed and used as a basis for quantifying the event tree, i.e., determining the likelihood of each pathway for a variety of accident sequence initiators. A generalized containment event tree code, called EVNTRE, has been developed to facilitate the quantification. The uncertainty in the results has been examined by performing the quantification three times, using a different set of input each time to represent the variation of opinion in the reactor safety community. In the so-called "central" estimate, the likelihood of early containment failure (occurring before or at the time of reactor vessel breach) was found to be very low for most accident sequence initiators. However, uncertainties surrounding the issues of direct containment heating, hydrogen generation and burning, and containment pressure capacity could lead to much higher early failure likelihoods. This work supports NRC's assessment of severe accident risks to be published in NUREG-1150.

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1. INTRODUCTION

This report, in several volumes, documents analyses performed under the Severe Accident Risk Reduction Program (SARRP) to investigate the response of containments at several commercial nuclear power plants to severe accidents. These analyses focus on identifying the various pathways that could lead to the release of fission products beyond the containment boundaries and on estimating their frequencies of occurrence. The analyses are part of an overall effort aimed at developing a comprehensive and up-to-date characterization of nuclear plant risk (Ref. 1) which will serve as a principal input to a forthcoming report by the U.S. Nuclear Regulatory Commission (NRC), NUREG-1150 (Ref. 2). It is anticipated that NUREG-1150 will provide a technical basis upon which to consider future decisions regarding changes to regulations and regulatory practices.

The analyses described in this report also provide a broader perspective on the significance of the fission product source terms estimated in NUREG-0956 (Ref. 3), in BMI-2104 (Ref. 4), and in subsequent analyses performed for SARRP (Ref. 5), by examining the ways in which containment failures leading to source terms of different magnitudes can occur.

One might ask, "Why is there a need for such a perspective on the various accident pathways that are possible?" To answer this question, let us consider as an example, the BMI-2104 analysis of the sequence S_2D at Surry. Two calculations were made. In the first, a break of a specified size (2-inch diameter) was presumed to occur in the cold leg through the reactor coolant pump seals, and the primary system coolant was presumed to end up in the containment sump. The emergency coolant injection system was assumed not to function. The containment was assumed to fail from rapid pressurization due to events occurring just after meltthrough of the reactor vessel, and the containment sprays were assumed to fail at that time. The release from containment was assumed to bypass the auxiliary building.

In the second calculation, a break of the same size was assumed to occur in the hot leg piping. Both the containment and the containment sprays were assumed to survive the events following vessel meltthrough, but the water flow to the reactor cavity was assumed not to prevent the core-concrete interaction from occurring. Containment remained intact until the calculation was terminated.

While the events assumed in the BMI-2104 calculations are plausible, one might ask whether they are the most likely series of events that could occur following sequence S_2D, or

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whether they produce the highest source terms that could occur within the realm of reasonable probability. Is it more likely, for example, that the size and location of the break would be different from what was assumed in BMI-2104; that the containment sprays would fail prior to containment failure, because of debris in the containment sump plugging the pump intakes; that containment might fail by some means other than early overpressurization; or that the release pathway would be through the auxiliary building, where further reduction of the source term would take place?

These questions raise the need for a systematic identification of the various pathways that the accident can take and assessment of the likelihood, or probability, of each. Such an analysis provides a basis for evaluating whether the source terms developed for a particular accident sequence cover the range of risk-significant source terms for that accident sequence.

The overall objectives of this study are (1) to identify accident pathways (i.e., combinations of accident sequences and containment events) that delineate source terms which may be important to risk, (2) to estimate the frequencies of those pathways and hence the frequencies of the source terms they attend, (3) to ascertain how well the BMI-2104 source terms cover the accident pathways that are important to risk, (4) to identify accident pathways for which additional source term calculations are needed, and (5) to provide important input for the SARRP assessment of risks (Ref. 1). These objectives have been implemented so far in assessments of four reference plants: Surry (PWR subatmospheric containment), Sequoyah (PWR ice condenser), Peach Bottom (BWR Mark I), and Grand Gulf (BWR Mark III). This volume describes the analyses for the Surry plant. Each of the other plants is treated in a separate volume of this report.

With regard to the nature of the sequences considered, two aspects should be noted. In the current analysis, we have not explicitly treated accidents initiated by external events (e.g., earthquakes, fires, flooding, etc), since no analyses of the frequencies of these events or of the capabilities of plant systems and structures to withstand them have been performed. In addition, we have not performed an in-depth evaluation of operator actions that might be taken to respond to core melt accidents to mitigate their consequences. The most serious obstacle to the performance of such an analysis is that plants do not currently have procedures which provide instruction to the operators past the onset of melting of the core; it is beyond the scope of the present analysis to devise such procedures and to evaluate their effects.

In Section 2, we will describe the method we used to achieve the objectives stated just above. First we will provide a general description of our containment event trees and the procedure we use for quantifying the branches. We will then illustrate this procedure by applying it to a specific sequence for Surry. Next, we will discuss the plant features which are important in the containment event analysis and the accident sequences which are to be analyzed. In Section 3, we will present the results, in terms of frequencies of containment failure modes for the various accidents that were assessed to be potential contributors to risk for Surry. In Section 4 we will summarize the results and comment on those that are particularly significant.

We have provided in Appendix A a sample problem for the containment event tree to facilitate the explanation of the manner in which the input for the event tree is structured. Appendix B presents our evaluations of the events in the containment event trees for Surry. Appendix B also provides the details of the example sequence treatment we discuss in Section 2. Appendix C includes the actual computer input for the containment event tree, while Appendix D presents the detailed computer output for three damage states.

The containment event trees developed by SARRP have been reviewed by a committee commissioned by NRC and consisting of representatives from the University of Wisconsin, Battelle Columbus Laboratories, Oak Ridge National Laboratory, Brookhaven National Laboratory, and Pickard, Lowe and Garrick, Inc. The review group investigated the reasonableness of the event trees (scrutability, completeness, consistency, and level of detail) and the reasonableness of the quantification (traceability, documentation completeness, coverage of sources, and consistency of approach). The review uncovered a few errors of logic and omission which have subsequently been corrected. Their detailed comments are provided in Reference 39.

2. METHOD

2.1 General Description and Observations

In traditional probabilistic risk assessments (PRAs), the accident pathways that contribute to risk are described by two types of event trees. "System event trees" are used to define the spectrum of accident sequences (i.e., the combinations of accident initiators and subsequent system failures) that can lead to core melting. "Containment event trees" are used to define the containment failure modes which lead to fission product releases beyond the containment boundary.

Our analyses are based upon the core-melt sequences that were developed and whose frequencies were estimated through the Accident Sequence Evaluation Program (ASEP, Ref. 6). For each of the reference plants, a probabilistic risk assessment (PRA) has been performed previously. The Surry plant was the PWR investigated in the Reactor Safety Study (RSS, Ref. 7). The sequence analysis from that study has been updated by ASEP to reflect the current plant configuration, accounting for changes that have been made to the plant since completion of the original study, and to incorporate improved risk assessment methods and data bases. A few planned, but not yet installed, plant modifications have been considered. These are modifications that are mandated by rulemaking and that have a specific time period by which they must be implemented.

In order to promote coordination between the sequence and containment analyses, the sequence results were also cast in the form of plant damage states. These plant damage states group sequences that would be expected to have similar effects on containment response. Although the same results could be obtained by evaluating containment response for the accident sequences, the plant damage states reflect explicit consideration of the sequence conditions that could produce unique effects on the likelihood of various containment failure modes (e.g., the status of containment safety features). They also provide a systematic mechanism for combining sequences that were distinguished for convenience in estimating their frequencies, but that need not be subjected to separate evaluation in the containment event tree. The definitions of the plant damage states for Surry are provided in Section 2.4.

Our primary focus is upon the containment event trees for Surry. We apply the event tree to particular sequences by selecting the appropriate branches within the event tree.

Our containment event trees are considerably expanded beyond those considered in previous PRAs. We ask the following types of questions:

(1) Entry states. What are the conditions in the reactor coolant system and containment prior to melting of the core that could influence the accident progression?

(2) Phenomenological events. What are the phenomena that could affect the progression of severe accidents, at what points during the accident timeline do they occur, and what are their subsequent effects on the accident development?

(3) Reactor coolant system failure modes. What is the size and location of the reactor coolant system breach and the pressure in the system at the time of breach?

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(4) Containment system survivability. Do the containment sprays, fan coolers, and suppression systems survive the conditions occurring during severe accidents that exceed their design bases?

(5) Containment failure modes. What are the loads that challenge containment, does containment survive these loads, what is the nature of the failure (approximate size and location), and what is the subsequent pathway for fission product release to the environment?

The questions on the containment event trees are posed in ways that require the answers to be expressed in terms of likelihoods. For a loss-of-coolant accident in a PWR, for example, we might ask how likely it is that the reactor coolant system breach will be in the cold leg piping as opposed to the hot leg piping; or how likely it is that containment will fail due to a hydrogen burn following reactor vessel failure. Answers to such questions require information about the reactor design, the phenomenology of reactor accidents, and the capabilities of containment. For example, to answer the two likelihood questions just posed, one would need to know about the characteristics of the cold leg versus hot leg piping, the amount of hydrogen generated prior to vessel breach, the availability of ignition sources, and the failure pressure of the containment.

Some of the issues addressed by the containment event trees are listed in Table 2.1. We point out that these are not the events themselves, but rather some of the issues that must be addressed in order for the event trees to be quantified.

We have utilized a large number of sources to obtain the needed information for Surry, including the following:

(1) Containment Loads Working Group (CLWG), References 8-10.

(2) Containment Performance Working Group (CPWG), Reference 11.

(3) Battelle calculations for the Accident Source Term Project Office (BMI-2104) and for SARRP, References 4-5.

(4) Quantitative Uncertainty Estimation for the Source Term (QUEST), Reference 12.

(5) Industry Degraded Core (IDCOR) program, Reference 13.

(6) Severe Accident Sequence Analysis (SASA) program, References 14-17.

(7) Severe Accident Uncertainty Analysis (SAUNA), Reference 18.

(8) Accident Sequence Evaluation Program (ASEP), Reference 6.

(9) SARRP Phenomena Assessment Task Force (PATF), Reference 19.

(10) Steam Explosion Review Group (SERG), Reference 20.

(11) High pressure ejection test series (HIPS), Reference 21.

(12) Available probabilistic risk assessments (PRA), References 7, 22-25.

(13) Final Safety Analysis Reports (FSAR), Reference 26.

(14) Architect-engineer (AE) and other estimates of containment failure pressure, References 27-28.

(15) Others, References 29-38.

The NRC provided general guidance with respect to the priorities to place upon the use of this variety of sources in evaluating the events in the containment event trees. To the extent possible, the information developed by the Containment Loads and Performance Working Groups and other analyses performed or sponsored by NRC were to be used. To provide a fuller treatment of issues raised in the containment event tree, other references, including analyses sponsored by the utility industry, were to be considered.

We encountered several difficulties in attempting to utilize information from these various sources. One of the most significant was incomplete coverage. Table 2.1 illustrates the relationship between some of the issues addressed by the event trees and the information provided by the two containment working groups and a number of the other programs. It is clear from the table that the results from the NRC-sponsored working groups and review groups do not address all of the questions asked.

When a question was addressed by one of the studies, the information provided often required us to make extrapolations. For example, the Containment Loads Working Group provided estimates of the size of steam spikes and direct heating for only the large-dry PWR reference plants, and then with preconditions appropriate for only one accident sequence. We had to extrapolate this information to other plants and other sequences. The same was true for the analyses of global

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hydrogen burns, diffusion flames, and containment temperatures achieved from core-concrete interactions. Similar statements apply to other studies.

Furthermore, the information provided to us often did not include a best-estimate characterization of a particular issue, but rather a range of possible values. For example, the CLWG provided low, medium, and high estimates for containment loading, whereas the CPWG provided only high estimates for containment leakage. In the CLWG, consensus was generally reached more often on the low and high estimates than on the medium estimates.

When we quantified our containment event trees, therefore, we propagated three separate estimates -- optimistic, central, and pessimistic. Thus, we derived three sets of accident outcome probabilities for each sequence. For each of the three estimates, we set up a set of branch point probabilities and parameter values that were different but each internally consistent. The set labeled "pessimistic" tends to provide higher probabilities for the pathways that lead to higher source terms and lower probabilities for the lower source term pathways. The sets labeled "central" and "optimistic" are analogously interpreted. In this report we do not propose weighting factors or distributions for these estimates, nor purport that one is more reasonable than another. We present the estimates as a reflection of the information that is available.*

We have attempted to define the three sets of values in such a way that the central estimate represents the median of the reactor safety community on any particular issue. That is, if a large number of experts were to be polled with regard to their views, a substantial fraction would respond that the actual situation would be better than that indicated by the central estimate, and an approximately equal number would respond that it is worse. Of those who responded that the situation is actually better than that represented by the central estimate, we would expect that a substantial number would view our optimistic estimate as an appropriate representation of the issue; likewise, those who viewed the situation as being worse than the central estimate implies would agree that reality is or could be as unfavorable as that reflected by our pessimistic estimate. It should be pointed out that we were not able to apply these principles rigorously in assessing some questions because, for some issues, there is a very small community of experts. In some cases, it was necessary for us to define the optimistic, central, and pessimistic estimates according to the views of one or two experts. For a few cases in which there was a very wide variety of opinions, indicating particularly large uncertainties, the issues were treated as sensitivities. This was specifically true for the assessments of direct heating and of an in-vessel steam explosion capable of causing containment failure (the α-mode). For these questions, we performed the sensitivity analysis by defining optimistic, central, and pessimistic values twice, once as the optimistic group would view them, and again as the pessimistic would. We then conducted two corresponding sets of optimistic/central/pessimistic walkthroughs. Generally, the optimistic views were that these phenomena were not physically possible, so that the sensitivity cases were effectively reduced to occurrence or non-occurrence of the phenomena.

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*In the SARRP risk report (Ref. 1), we explore the question of reasonableness by developing and implementing a second procedure of uncertainty evaluation called "limited Latin hypercube." That procedure uses expert opinion to establish weighting factors, which are used as a basis for sampling a number of uncertain issues. The two methods were found to give comparable results.

Finally, our containment event analysis is based on the plant configurations that currently exist. We have not attempted to account for plant changes that are planned but not yet implemented, with the exception that changes mandated by rulemaking are included even if they have not yet been installed. This exception had a larger impact for the BWR plants than for the PWRs. For example, in our analysis for Peach Bottom, we account for the symptomatic emergency procedures that include containment venting, alternate injection sources, and procedures for anticipated transients without scram, and we do credit the increased standby liquid control capacity, since it is mandated by the ATWS rulemaking.

It is worth noting that in this report we describe only the accident pathways leading to fission product releases, and do not calculate the source terms. The source terms for these accidents are being documented in a separate report (Ref. 5). The pathways and corresponding source terms are integrated through the performance of consequence analyses to provide a characterization of risk; this process and the results, including an assessment of the impact on risk of various potential safety measures, are described in the SARRP risk rebaselining and risk reduction report, Ref. 1.

2.2 Specific Example: Surry S_2D_1

The general event tree for large, dry PWR containments includes a total of 59 questions. These questions cover all the accident sequences which we analyzed for the Surry plant.

Table 2.2 provides a list of the questions together with references to prior questions upon which the answers depend, in effect outlining the structure of the event tree.

Tables 2.3 through 2.5 illustrate the application of the method by providing the details for accident sequence S_2D_1. This sequence is initiated by a small reactor coolant system break. The emergency core cooling system fails to inject water onto the core. Containment sprays are operative as the accident develops toward a core meltdown.

About half of the questions in Table 2.2 are applicable to the S_2D_1 sequence in Surry. For those questions, we have provided in Table 2.3 an itemization of the branches that are applicable and of the corresponding answers that we assigned for the specific sequences being evaluated. It should first be observed that for some of the questions there are more than two branches. In these cases, the answers are not expressed as "yes" or "no", but rather as a choice among possible break sizes, break locations, or degrees of damage.

Next it should be noticed that some of the answers are expressed numerically and others are expressed verbally. This distinguishes the fact that for some questions the available information is sufficient to make quantitative estimates of likelihood, while for others the data supports only qualitative likelihood descriptors. Ultimately, we will assign numerical values to the qualitative descriptors in order to evaluate the frequencies of containment failure modes. However, we will recognize that this assignment of numbers is highly subjective and will accordingly evaluate the sensitivity of the results to the numerical choices. This aspect of the work will be discussed further in Sections 2.3 and 3.2

For many of the questions addressed in Table 2.3, information is needed about containment loading and containment capacity. In Table 2.4, we provide the results of our evaluations of containment loading for various accident situations. We give containment capacities (both for structural failure and for induced leakage) in Table 2.5. Table 2.6 provides the basis for estimating containment loading from direct heating and steam spikes.

The detailed rationale for our assignment of values in Tables 2.3, 2.4, 2.5, and 2.6 is provided in Appendix B.

2.3 Treatment of Verbal Descriptors

Interpretation of words such as "likely", "indeterminate", "unlikely", or "remotely possible" in Table 2.3 is subjective. In cases where we have used these words, we did so because there was no clearcut way to quantify the likelihoods of the questions being asked. Still, some assignment of numerical values is necessary if the frequencies of the outcomes are to be estimated.

Table 2.7 shows four plausible assignments of values for the verbal descriptors we have used. In most cases, we used Alternative 1 to quantify the outcome frequencies; however, we also investigated the sensitivity of some of the results to the choice of quantification alternatives. The results of the sensitivity study are described in Section 3.2.

2.4 Summary of Plant Features and Accident Sequences

In this section, we will discuss specific reactor plant features which shape the form of the containment event tree and will describe the various accident sequences which have been quantified for Surry. Details of the event tree construction and quantification is provided in Appendix B.

2.4.1 Plant Features Important to Containment Response

Several features of the Surry containment make it unique relative to its response to a core melt accident. The Surry containment is maintained at subatmospheric pressure (at approximately 10 psia) during normal operation in order to help limit the peak pressure that would be realized during accident conditions. This aspect of the design has an added benefit relative to the likelihood that a significant leakage path from containment exists at the onset of an accident. It is quite likely that the operators at Surry would be alerted to the presence of a leak of any consequence due to the cycling of the vacuum pumps as they attempted to maintain the containment at the desired pressure. A relatively large pre-existing leak would be virtually precluded by the fact that the vacuum pumps would be unable to prevent the containment from approaching atmospheric pressure; the operators would be forced to terminate the leakage path or to bring the plant to a stable shutdown condition.

One of the more important features of the containment design is the pressure at which serious failure could be expected to occur. The capacity is a key determinant in the likelihood and timing of containment failure during pressure transients that result from the generation of steam or combustion of hydrogen, and the pressure at containment failure can also influence the dispersion of fission products released to the environment.

The Surry containment is a cylindrical, domed, steel-reinforced concrete building with a steel liner. We based our estimates of the pressure capacity upon analyses performed for the RSS (Ref. 7) and by Stone and Webster (S&W, Ref. 27). The RSS assessed the mean failure pressure to be 85 psig with a standard deviation of 15 psi, judging the likely failure mechanism to be tearing of the containment liner. The S&W evaluation obtained a failure pressure of 119 psig, but did not report an estimate of the possible variance in this value. A similar assessment performed for the Zion Probabilistic Safety Study (ZPPS, Ref. 23) estimated a standard deviation of 2.5 psi. We combined the results of these three evaluations to obtain our optimistic, central, and pessimistic estimates for the pressure capacity:

Optimistic estimate	Mean = 119 psig Standard deviation = 2.5 psi
Central estimate	Mean = 119 psig Standard deviation = 15 psi
Pessimistic estimate	Mean = 85 psig Standard deviation = 15 psi

The ability to maintain pressure within the capacity of the containment is largely affected by the availability of systems that remove heat from the containment atmosphere. Two active systems for containment heat removal are reflected in the general containment event tree for PWRs with large, dry containments: a containment spray system and a fan-cooling system. For Surry, there is no fan-cooling system for emergency conditions.

The containment spray system consists of six trains, two of which are capable of injecting water from the RWST into containment. Both of the injection trains are actuated when containment pressure reaches approximately 10 psig. The other four trains are actuated after spray injection is initiated, drawing suction from the containment sump and recirculating back to the spray headers. The pumps for two of these recirculation trains are located outside containment, and the other two are inside. For an initial period after they are actuated, the outside spray pumps require some flow to be diverted to their suction from the discharge of the injection pumps in order to assure that the flow from the containment sump is adequately subcooled. Each of the four recirculation trains has a heat exchanger, providing for rejection of containment heat to a service water system.

These spray recirculation systems take on added significance since they are the principal means of removing decay heat following a LOCA or other event in which the containment serves as the heat sink for emergency core cooling systems. Therefore, there is the potential for failure of containment heat removal to lead to both a loss of core cooling and to overpressurization of the containment.

The design of the reactor cavity can have an important impact on both the challenges to containment integrity following failure of the reactor vessel, and the release and dispersion of fission products within containment. These impacts result primarily from three design aspects: (1) the degree to which the core debris is inhibited from being dispersed following ejection from the reactor vessel, (2) the ability of water in containment to reach the core debris, and (3) the capability to transfer heat from the cavity to the containment atmosphere.

At Surry, the reactor cavity does not communicate directly with the containment sump. Thus, the amount of water present in the cavity at the time that the reactor vessel is breached depends strongly on the nature of the core-melt sequence and the operation of the containment spray system. If the spray system is functioning, a significant quantity of water will reach the reactor cavity. Otherwise, the cavity will be relatively dry, except for the water remaining in the reactor vessel at the time of the melt ejection. The inventory of the cold-leg accumulators may also discharge to the cavity after the vessel breach, if the core melt has progressed at relatively high pressure (e.g., for very small LOCAs and transients with cycling pressurizer relief valves).

2.4.2 Description of Surry Accident Sequences

The accident sequences assessed to be important for Surry are most easily described in the context of the plant damage states into which they are grouped. The plant damage states for Surry reflect consideration of several parameters that could have an impact on the progression of a core melt accident:

- The size and location of the breach in the reactor coolant system,
- Whether or not there is water in the reactor cavity at the time of the breach of the reactor vessel following core melt,
- The status of the containment spray and heat removal systems,
- Whether the sequence involved failure of the containment prior to melting of the core, and
- Whether or not the accident involved a bypass of containment.

From this list, a set of four parameter categories was developed. The possible states for each of these categories were assigned a letter, leading to the definition of four-character designators for each plant-damage state. The parameter categories and their states are as follows:

1. The integrity of the RCS pressure boundary:

    A LOCA leading to low pressure in the RCS prior to breaching of the reactor pressure vessel,

    S_2 Small LOCA leading to intermediate pressure in the RCS prior to breaching of the reactor pressure vessel,

    S_3 Very small LOCA, with high pressure in the RCS prior to breaching of the reactor pressure vessel,

    T RCS is essentially intact and at high pressure prior to the vessel breach (the pressurizer relief valves may be cycling), and

    V LOCA that bypasses the containment boundary.

2. Whether or not water from the RWST has been discharged into containment:

    Y The RWST inventory has been discharged to containment, either by the emergency injection systems or by the containment spray injection system, and

    N The RWST inventory has not been discharged to the containment.

3. Whether or not containment heat removal is available:

    Y Containment heat removal is available, and

    N Containment heat removal is not available.

4. The status of the containment spray systems:

    B Both the containment spray injection and the containment spray recirculation systems are available.

    I The containment spray injection system is available, but the recirculation systems have failed,

    R Containment spray recirculation is available, but the injection system failed (possible in Surry because of the separate systems for injection and recirculation), and

    N Neither injection nor recirculation flow is available.

Many of the possible combinations are not of interest (for example, for a bypass of containment, the status of the containment spray system is not very important) or are not physically meaningful (e.g., if the RWST inventory has not been discharged to containment, it is not possible for containment spray injection to have functioned). The plant damage states for Surry are summarized in Table 2.8.

Plant damage state V represents a single sequence, the occurrence of an interfacing systems LOCA. This sequence involves the failure of the two series check valves in the low pressure injection lines that normally isolate reactor coolant system pressure from the low pressure injection system, which has a much lower design pressure. Overpressurization of the low pressure system could cause a LOCA outside containment, resulting simultaneously in failure of the injection system. Because the sequence results directly in the bypass of the containment, it was not necessary for us to perform a walk-through of the containment event tree. The magnitude of the resulting release can be mitigated somewhat if the break in the low pressure system occurs at a location that would be submerged by water discharged from the reactor coolant system and the RWST, such that there is substantial scrubbing of the fission products.

Plant damage state AYYB includes sequences initiated by large or intermediate LOCAs, with the spray system functioning to provide containment heat removal. ASEP assessed the damage state to be dominated by four sequences with similar frequencies: AH_1 and S_1H_1 (large and intermediate LOCA, respectively, followed by failure of the low pressure recirculation system); S_1D_1 (intermediate LOCA with failure of high pressure injection); and AD_5 (large LOCA with failure of the cold leg accumulators to discharge). For this damage state, function of the sprays helps to limit the potential for steam overpressurization, but also ensures that the containment atmosphere does not become steam inerted, so that there is a better chance for a hydrogen burn. The spray operation also ensures that there is a large quantity of water on the containment floor and in the reactor cavity, making it more likely that a coolable debris bed will form and limiting the potential for core-concrete interactions.

Sequences initiated by a large or intermediate LOCA with the containment spray system unavailable in both the injection and recirculation modes are assigned to damage state ANNN. The two sequences that contribute to this damage state are ACD_6, a large LOCA with failure of the low pressure injection system, and S_1CD_1, an intermediate LOCA with failure of the high pressure injection system. For this damage state, there is only a limited amount of water in the containment at the time of vessel failure, and the spray system is not available, so that a coolable debris bed cannot be formed.

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Plant damage state S_2YYB is similar to AYYB, except that there is a much smaller rate of leakage to the containment from the reactor coolant system and the core melt progresses at relatively high pressure. The sequences contributing to this damage state include S_2D_1, S_2H_1, and S_2H_2 (small LOCA with failure of high pressure injection, low pressure recirculation, and high pressure recirculation, respectively). A sequence involving failure to scram when the moderator temperature coefficient is at an unfavorable value was also assigned to this damage state. For this damage state, there is a small chance that the spray system will not be actuated, if there is a failure of containment isolation sufficient to prevent the containment pressure from reaching the spray setpoint prior to failure of the reactor vessel.

Sequences involving a small LOCA leakage rate from the reactor coolant system with failure of the containment sprays in both the injection and recirculation modes are assigned to plant damage state S_2NNN. Sequence $T_1QD_1CF_1$, which is a station blackout (i.e., loss of offsite power and failure of the onsite emergency power system) and failure of a pressurizer safety valve to reclose after opening on the initial pressure transient, dominates the frequency of this damage state. In this case, there is again a limited amount of water in the containment, and the spray system is not available to provide heat removal from the containment. Consideration was given to the potential for recovery of electric power late in the accident, permitting operation of the sprays, which could both reduce containment pressure and increase the likelihood of a damaging hydrogen burn, since they would tend to de-inert the containment atmosphere.

Plant damage state S_3YYB is similar to S_2YYB, except that the sequences are initiated by very small LOCAs, and the core melt progresses at high pressure. The sequences contributing to this damage state include S_3D_1, S_3H_1, and S_3H_2 (very small LOCA with failure of high pressure injection, low pressure recirculation, and high pressure recirculation, reespectively). The containment sprays operate throughout the sequence.

Plant damage state S_3NNN includes sequences involving a very small LOCA with the containment spray systems unavailable. The damage state was assessed to be dominated by sequence $T_1(SL)D_1CF_1$, which is a station blackout (i.e., loss of offsite power and failure of the onsite emergency power system) followed by failure of the reactor coolant pump seals due to the loss of all seal cooling. Once again, the spray failure limited the quantity of water in the containment, unless electric power was recovered late in the accident.

Plant damage state TYYB is virtually identical to S_3YYB; they were distinguished primarily because of the differences in the initial break locations (cycling pressurizer relief valves vs. failure of the reactor coolant pump seals). The frequency of the damage state was assessed to be dominated by sequences T_1LP (transient with failure of auxiliary feedwater and failure of the PORVs to operate to effect feed-and-bleed cooling) and TKRD$_4$ (ATWS with failure of high pressure injection for emergency boration). We assessed the containment response to be equivalent to that for damage state S_3YYB.

Similarly, plant damage state TNNN is equivalent to damage state S_3NNN. It is dominated by two station blackout sequences, one involving failure of the turbine-driven auxiliary feedwater pump (sequence T_1L(ST)DCF$_1$), and the other including failure to recover electric power prior to depleting the station batteries (sequence T_1L(LT)DCF$_1$).

All of the other plant damage states were assessed to have negligible frequencies.

3. RESULTS

The results of the containment event analysis are presented in this section. The results for particular sequences are described in some detail and tabulated. Each of these sequence tables has three parts. The first is the sequence frequency as estimated by ASEP. The second part of the table gives the containment failure mode probabilities for the optimistic, central, and pessimistic walkthroughs. Two cases are presented for the central and pessimistic analyses. Case 1 excludes in-vessel steam explosion and ex-vessel direct heating phenomena, and case 2 includes them. (In the optimistic walkthrough, these either do not occur or have negligible effect so the two cases are not differentiated.) The third part of each table describes the principal containment pathways and whether a calculation was made for them in BMI-2104.

The results are also tabulated in a more condensed format for all of the plant damage states. These tables present, for each damage state, the containment failure modes that were identified as important for source term considerations in our binning meetings with BCL and other laboratories.

3.1 Sequence Results for Surry

The results for Surry are presented in Tables 3.1 through 3.8. The first three tables, 3.1 through 3.3, provide a somewhat detailed presentation of results for three sequences: S_2D_1 (a small LOCA with failure of high pressure injection, equivalent to sequence S_2D from the RSS); T_1LDCF$_1$ (a transient followed by failure of all auxiliary feedwater, failure of feed-and-bleed cooling and failure of the containment spray system; it is equivalent to sequence TMLB' from the RSS, which involved total loss of ac power and failure of the turbine-driven auxiliary feedwater pump); and ACD_6F_1 (a large LOCA with failure of injection and failure of the containment spray system; it is equivalent to sequence AB from the RSS). The important pathways for the sequences are also described below. Tables 3.4 through 3.8 provide a more condensed summary of results for all the plant damage states. These results are described in Section 3.1.4.

3.1.1 Sequence S_2D_1

The results for sequence S_2D_1 at Surry, shown in Table 3.1 for the three different walkthroughs, range from no containment failure in the optimistic case to nearly assured failure at the time of vessel breach in the pessimistic case.

In the optimistic case, virtually all of the sequence frequency is associated with no containment failure. In this walkthrough, the formation of coolable debris beds is considered very likely and the failure of sprays during the accident progression considered very unlikely. Thus a safe stable state is achieved wherein the decay heat is removed by the containment sprays, and the containment does not fail.

In the central estimate analysis, spray failure after vessel breach due to debris in the containment recirculation sump is considered unlikely, but formation of a coolable debris bed is also considered unlikely. Further, the reactor cavity is flooded at the time of vessel breach, reducing the potential for direct heating of the containment atmosphere. This scenario results in the shift from no containment failure to late containment failure due to either basemat meltthrough or gross overpressurization from production of noncondensibles.

In the pessimistic walkthrough, containment failure at vessel breach, either due to direct heating or a combined steam spike and hydrogen burn, dominates the results. The estimate of 100% zirconium oxidation by the time of vessel breach in this walkthrough produces the high probability of failure due to a steam spike and hydrogen burn in Case 1. These phenomena, in combination with larger fractions of the core participating in direct heating, give rise to nearly assured containment failure in Case 2.

3.1.2 Sequence T_1LDCF_1

The results for sequence T_1LDCF_1 at Surry are shown in Table 3.2. They are similar in character to the results discussed earlier for sequence S_2D_1, but there are some

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differences. The differences arise primarily due to ac power considerations. In sequence T_1LDCF_1, ac power is initially unavailable. However, our analyses considered that it was likely that ac power would be recovered late in the accident. This has several effects. First, since power is unavailable early, containment heat removal is also unavailable, so the containment becomes inert due to high steam concentrations early in the accident. This prevents any hydrogen combustion at the time of vessel breach, thus eliminating the possibility of failing containment at this time due to a combined steam spike and hydrogen burn. A second effect is that when ac power and containment heat removal are restored late in the accident, the containment is essentially de-inerted, so the hydrogen which has accumulated in the interim can then combust. This provides the opportunity for late containment failure due to a hydrogen burn. The third effect is that if power is not restored, containment failure cannot be prevented. The containment will ultimately fail either from basemat meltthrough or overpressurization. In addition, because the RCS may remain pressurized and the steam generators are dry, there is pessimistically a small probability (~10%) that a small steam generator tube leak will be induced. Other differences relative to S_2D_1 include the relative dryness of the reactor cavity and the potential for the RCS to remain at higher pressures prior to vessel breach. These factors make direct heating somewhat more likely. In other pathways for T_1LDCF_1, the reactor coolant system depressurizes due to the occurrence of an induced LOCA. Direct heating is less of a factor for these pathways, since there is reduced driving force for dispersal of core debris.

3.1.3 Sequence ACD_6F_1

The results for the three walkthroughs (optimistic, central, and pessimistic) for sequence ACD_6F_1 at Surry are summarized in Table 3.3. The results are dominated by either no containment failure or late containment failure. With the exception of failure of containment due to a missile from an in-vessel steam explosion, the results are identical for Case 1 and Case 2. This is to be expected since for a large LOCA the RCS is at nearly ambient pressure so there is no driving force for the direct heating phenomenon.

In the optimistic analysis the majority of the event tree outcomes result in no containment failure. This ensues from considerations that a coolable debris bed will likely be formed and that ac power, and hence containment heat removal, will be restored. However, there is still some chance that the debris will not be coolable. This possibility coupled with the chance that power will not be restored leads to moderate chances of late containment failure due to basemat meltthrough and late pressure induced leakage.

In the central walkthrough, pressure-induced containment leakage sufficient to preclude overpressure is considered less likely and larger amounts of zirconium are oxidized. This leads to a shift away from the no containment failure and pressure-induced leakage categories of the optimistic walkthrough toward the containment failure categories of late hydrogen burns and gross overpressure.

In the pessimistic analysis the results show practically no chance of avoiding containment failure, but the failures are still dominated by late containment failure modes. The most notable change from the results of the central case is that containment failure due to gross overpressurization dominates. This arises because both coolable debris bed formation and pressure-induced leakage sufficient to preclude overpressurization are considered as very unlikely.

3.1.4 Results for the Plant Damage States

The results of the containment analyses for each of the potentially important plant damage states are summarized in Tables 3. through 3.8 for the optimistic, central and pessimistic walkthroughs for the cases without direct heating and the in-vessel steam explosion, and for the central and pessimistic walkthroughs for the cases with these phenomena included. The tables present the likelihoods of the various containment release modes determined to be of interest relative to the release of fission products. The release modes are as follows:

1. The containment remains intact throughout the accident.

2. The core debris penetrates the containment basemat, with the containment sprays functioning throughout the accident.

3. Penetration of the basemat with the sprays inoperable.

4. There is long-term overpressurization by the generation of steam and noncondensible gas as a consequence of core-concrete interactions, resulting in leakage sufficient to prevent further pressurization but insufficient to produce rapid depressurization.

5. Rupture of the containment late in the accident occurs due to the generation of steam or the burning of hydrogen and other flammable gases generated from core-concrete interactions. The containment sprays are available.

6. Late rupture of containment occurs, as in 5, but with the spray system unavailable.

7. Rupture of the containment occurs before or at the time of reactor vessel failure, with the reactor coolant system at high pressure and with the containment spray system operating. The failure modes include early burning of hydrogen generated during the core degradation process; failure at the time of vessel failure due to the steam spike generated when the core debris is discharged into the water in the cavity, due to direct heating or an in-vessel steam explosion (for that sensitivity case); or failure due to the burning of the hydrogen released at the time of vessel failure.

8. Early rupture of containment occurs, as in 7, but with the spray system unavailable.

9. The containment ruptures before or at the time of reactor vessel failure, with the reactor coolant system not at high pressure and with the containment sprays operating. The failure modes are similar to those in 7, except that the lower pressure provides insufficient driving head for the core debris to be dispersed in a manner that could lead to direct heating of the containment atmosphere.

10. Rupture of containment occurs, as in 9, but with the containment spray system not available.

11. Containment isolation fails, leading to significant leakage (equivalent to a leak area of >4.0 in^2), with the spray system operating.

12. Large containment isolation failure occurs without the containment sprays operable.

13. Containment failure prior to core melt occurs due to failure to remove heat from the containment atmosphere, but with the spray system continuing to operate.

14. Containment overpressurizes prior to core melt with the containment spray system rendered inoperable at the time of containment failure.

15. Containment is bypassed, with the point of release at a location that would be submerged.

16. Containment bypass occurs with no submergence of the point of release.

The plant damage state AYNB merits particular attention; it represents the failure of containment preceding core melt (failure modes 13 and 14 above). The sequences assigned to this damage state involve LOCAs with failure of the service water cooling for the containment heat exchangers. The containment eventually overpressurizes, potentially resulting in the failure of emergency coolant recirculation. The sequence is therefore particularly significant because the containment is assured of being failed, and since the failure occurs prior to core melt, there is reduced potential for the holdup of fission products in containment.

3.2 Sensitivities

As mentioned in Section 2.3, the numerical values assigned to verbal descriptors such as "unlikely" or "remotely possible" are somewhat arbitrary, and the results could be sensitive to these choices. Accordingly, we performed a sensitivity study for an example sequence similar to Surry S_2D_1 using the four alternative numerical sets in Table 2.7. The results, depicted in Table 3.9, indicate that the variation of conditional probability within each walkthrough (optimistic, central, pessimistic) is small compared to the difference in results between walkthroughs.

Although the results are not very sensitive to the choice of numerical values, they are sensitive to the choice of verbal descriptors, i.e., whether phenomena are considered "likely" or "unlikely" to occur. This sensitivity has been covered by the choice of optimistic, central, and pessimistic walkthroughs.

4. SUMMARY AND CONCLUSIONS

To interpret our results in the most illuminating way, it is necessary to clarify the meanings of the words "optimistic", "central", and "pessimistic". For this purpose, let us offer the following observations. Our central estimates are intended to provide a glimpse of the median of the reactor safety community. That is to say, we have a reasonable expectation that if the community were polled on the subjects treated in this document, a substantial fraction would respond that the reality of the situation is better than that depicted by our central estimates, and a comparably substantial fraction would respond that it is worse. Among those who think that reality is better (a group that we could refer to as "optimists"), a substantial fraction would claim that it is or could be as benign as our optimistic estimates imply. Similarly, many of the opposing group (the "pessimists") would claim that reality is or could be as unfavorable as our pessimistic estimates imply.

Again, it should be pointed out that we were not able to apply these guidelines rigorously as a consequence of the small number of experts whose views were available on particular issues. The effects in these circumstances are illustrated by sensitivity studies performed for issues with very large uncertainties.

Viewed in this context, the results of our containment event analyses indicate quite clearly that there are large uncertainties in the reactor safety community's understanding of containment loading and response. The differences between the optimistic and pessimistic results attest that for many accident sequences, one cannot state the probabilities of the containment release modes within narrow limits. However, one can identify the factors that drive the results and understand the reasons for the differences.

Fortunately, there are a limited number of factors that are governing, and they can be readily identified from our analysis. In the paragraphs below, we shall summarize, the principal features of our results and the factors that drive them. In the process, we shall attempt to identify the sources of uncertainty which are principally responsible for the differences between the views of the optimist and the pessimist. Of course, the discussion will be limited only to those sequences which we have analyzed.

In the central walkthrough, the likelihood of early containment failure (before or at the time of vessel breach) has been estimated to be negligible for most sequences. The principal exceptions are sequences initiated by loss of service water cooling to the containment heat exchangers. In such sequences, containment failure may be the cause of core cooling interruption. Early containment failure (at the time of vessel breach) is also plausible for the station blackout sequence, owing to the possibility of significant direct heating. However, the likelihood of early failure in the central estimate for station blackout is very low (0.5%). For all core melt sequences other than those initiated by failure of service water, there is a reasonable likelihood that containment will not fail at all.

In the pessimistic walkthrough, the likelihoods of early containment failure modes are much higher. There are two causes, either of which is sufficient to produce the result. The first is the pessimistic assessment of direct heating; the second is the pessimistic view regarding the coincident occurrence of a steam spike and hydrogen burn at the time of vessel breach. Factors which could reduce the importance of these phenomena in the pessimistic walkthrough are (1) less hydrogen generation, (2) a less coherent meltdown, (3) occurrence of temperature-induced failures in the reactor coolant system, and (4) a significantly higher containment failure pressure. Induced steam generator tube ruptures that could lead to a partial bypass of containment are potentially

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important for sequences where the reactor coolant system pressure remains high (e.g., TMLB'). In-vessel steam explosions could also be important in the pessimistic walk-through if experiments and analyses were to show that their influence is greater than believed at the time these analyses were performed.

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Table 2.1. USE OF INFORMATION SOURCES IN ADDRESSING THE ISSUES IN THE CONTAINMENT EVENT TREE

ISSUE	INFORMATION SOURCES[a]												
	CLWG	CPWG	BMI-2104	QUEST	IDCOR	SASA	SAUNA	PTAF	SERG	HIPS	PRA	LE	OTHERS
1. Size of Preexisting Containment Leakage	--	X	--	--	X	--	--	--	--	--	X	--	X
2. Size and Location of the Primary System Break During the Melt Release (e.g., Hot Leg vs. Cold Leg).	--	--	--	--	--	--	--	--	--	--	--	--	--
3. Timing of Accumulator Discharge Relative to Timing of Reactor Vessel Breach.	--	--	X	--	X	X	--	--	--	--	X	--	X
4. Occurrence of In-Vessel Steam Explosion Large Enough to Fail the Reactor Vessel.	--	--	--	--	--	--	X	--	--	--	--	--	X
5. Occurrence of In-Vessel Steam Explosion Large Enough to Fail the Containment.	--	--	--	--	X	--	X	--	X	--	X	--	X
6. Timing and Magnitude of Early Hydrogen Burns.	X	--	X	--	X	X	X	X	--	--	X	--	X
7. Magnitude of the Ex-Vessel Steam Spike	X	--	X	X	X	X	X	X	--	X	X	--	X
8. Extent of Direct Heating of the Atmosphere Following Vessel Breach.	X	--	--	--	X	--	--	--	--	X	--	--	--
9. Containment Structural Failure Pressure	--	--	--	--	X	--	--	X	--	--	X	X	--
10. Size of Containment Leakage Induced by Temperature or Pressure.	--	X	--	--	X	--	--	--	--	--	--	--	--
11. Survivability of Containment Sprays at Various Times During the Accident.	--	--	--	--	X	--	--	--	--	--	X	--	X
12. Extent of Core-Concrete Interaction	X	--	X	--	X	X	X	--	--	--	X	--	X
13. Timing and Magnitude of Late Hydrogen Burns	X	--	X	--	X	X	--	--	--	--	--	--	X
14. Potential for Direct Core Debris Attack on Containment Structures	X	--	--	--	--	--	--	--	--	--	--	--	--
15. Potential for Core Debris to Melt Through the Basemat	--	--	X	--	X	--	X	--	--	--	X	--	X
16. Potential for Basemat Meltthrough to Cause a Depressurization of Containment	--	--	X	--	--	--	X	--	--	--	X	--	--
17. Potential for Effluent to Pass Through Adjacent Structures, Such as the Auxiliary Building	--	--	X	--	X	--	--	--	--	-	--	--	--

[a]Information sources used in evaluating a particular issue are denoted by an "X".

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TABLE 2-2. EVENT DESCRIPTIONS FOR PWR SUBATMOSPHERIC AND LARGE-DRY CONTAINMENTS

	QUESTION ASKED BY EVENT TREE	PRIOR QUESTION DEPENDENCIES
1.	Is ac power available after the initiating event?	None
2.	Does core water makeup fail before containment overpressurization?	None
3.	What is the level of preexisting containment leakage or isolation failure?	1
4.	Where is the initial reactor coolant system break?	None
5.	What is the size of the initial reactor coolant system break?	None
6.	Is the containment initially bypassed?	4
7.	Are the steam generators wet or dry?	None
8.	Do the fan coolers fail to actuate before core degradation?	*
9.	Do the containment sprays fail to actuate in the injection mode before core degradation?	1,3,5,6
10.	Do the containment sprays fail to actuate in the recirculation mode before core degradation?	9
11.	To what degree, if any, is the auxiliary building initially bypassed?	3,4,7
12.	Where, if at all, is there a temperature-induced failure of the reactor coolant system during the period of core degradation?	5
13.	What is the size of the temperature-induced reactor coolant system failure?	12
14.	What is the primary system pressure during core degradation? Also, what would be the containment pressure increment from a primary system blowdown?	5,12
15.	At what level, if any, is containment bypassed during core degradation?	4,5,12,13
16.	What is the rate of blowdown to containment during core degradation?	5,6,13,15
17.	Do the containment sprays fail to actuate during the period of core degradation?	1,3,10,16
18.	Is there containment heat removal during core degradation?	8,17
19.	At what level, if any, does containment fail due to steam pressurization before vessel breach?	2,3,15,18
20.	What is the containment pressure before vessel breach?	3,16,18,19
21.	Is there a hydrogen burn before vessel breach? Also, what is the pressure increment from such a burn?	3,16,18
22.	Does containment fail because of a hydrogen burn before vessel breach? Also, what is the associated failure pressure and standard deviation?	20,21
23.	To what degree, if any, is the auxiliary building bypassed before vessel breach?	7,11,12,19,22
24.	Do the fan coolers fail after the early hydrogen burn?	*
25.	Do the containment sprays fail after the early hydrogen burn?	1,17,21,22
26.	Is there containment heat removal after the early hydrogen burn?	24,25
27.	What is the mode of reactor vessel breach?	14
28.	Does direct heating of the containment atmosphere occur just after vessel breach? Also, what is the pressure increment from a steam spike alone and from a steam spike plus direct heating?	14,17,27
29.	Is there a hydrogen burn just after vessel breach? Also, what is the pressure increment from such a burn? Also, what is the associated failure pressure and standard deviation?	3,16,21,26
30.	Does containment fail due to a steam spike, direct heating, and/or hydrogen burn just after vessel breach?	14,20,28,29
31.	What is the mode of containment failure, if any, just after vessel breach?	3,19,22,27,28 29,30

TABLE 2-3. EVENT DESCRIPTIONS FOR PWR SUBATMOSPHERIC AND LARGE-DRY CONTAINMENTS (Cont'd)

	QUESTION ASKED BY EVENT TREE	PRIOR QUESTION DEPENDENCIES
32.	To what degree, if any, is the auxiliary building bypassed just after vessel breach?	23,31
33.	Do the fan coolers fail after vessel breach?	*
34.	Do the containment sprays fail after vessel breach?	1,25,31
35.	Is there an oxidation release?	27,28
36.	Is ac power restored after vessel breach?	1
37.	Do the fan coolers fail late in the accident?	33,36
38.	Do the containment sprays fail late in the accident?	34,36
39.	Is there containment heat removal late in the accident?	37,38
40.	Has the contents of the refueling water storage tank been injected into containment?	9,17,25,34,38
41.	What is the amount of water injected into containment?	2,14,16,40
42.	Do significant core-concrete interactions occur after vessel breach?	14,18,27,34,41
43.	Is ac power recovered late in the accident?	1
44.	What is the internal pressure late in the accident?	26,39,40,42
45.	Has a large leak or gross failure occurred late in the accident?	3,15,19,22,31
46.	Does a late hydrogen burn occur?	21,29,39,44,45
47.	What pressure rise would occur if combustible gases were to burn late in the accident?	28,42,43,46
48.	Would containment fail due to a late hydrogen burn or steam production?	44,47
49.	In what way, if at all, does containment fail due to gradual pressurization from boiloff of water or noncondensible gases or hydrogen burning (leakage or gross rupture)?	45,46,48
50.	To what degree, if any, is the auxiliary building bypassed late in the accident?	32,49
51.	Do the fan coolers fail after the late hydrogen burn?	*
52.	Do the containment sprays fail after the late hydrogen burn?	38,46,49
53.	Is there containment heat removal very late in the accident?	51,52
54.	Is there a vaporization release?	17,25,34,42
55	To what degree, if any, does containment leakage occur due to high temperatures very late in the accident?	41,45,48,53
56.	Does basemat meltthrough occur, given no prior containment failure?	26,38,39,42, 45,48,53,54,55
57.	Does containment depressurize after basemat meltthrough?	26,39,53,56
58.	What is the ultimate containment failure mode, if any, resulting from core-concrete interactions?	42,45,48,53, 55,56,57
59.	To what degree, if any, is the auxiliary building ultimately bypassed very late in the accident?	50,55,57

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*Not applicable for Surry.

TABLE 2.3. EVENT DESCRIPTIONS AND LIKELIHOODS FOR SURRY S_2D_1

EVENT	PRIOR EVENTS	BRANCHING OPTIONS	LIKELIHOOD		
			OPTIMISTIC	CENTRAL	PESSIMISTIC
3 Preexisting containment leakage or isolation failure		(i) Tech. specs. or less	0.987	0.970	0.949
		(ii) Greater than tech. specs. but insufficient to preclude gradual overpressurization later in accident	0.013	0.020	0.051
		(iii) Greater than (ii) but insufficient to depressurize containment in about 2 hours	0.0	[illegible]	0.002
		(iv) Greater than (iii)	0.0	0.0	0.0
4. Initial reactor coolant system break location		(i) Hot Leg	Unlikely	Unlikely	Unlikely
		(ii) Cold Leg	Likely	Likely	Likely
		(iii) Other	0.0	0.0	0.0
9. Containment Spray Failure to Actuate Before Core Degradation	(a) No Large Containment leakage or bypass (level iii or greater)		0.0	0.0	0.0
	(b) Large containment leakage or bypass (level iii or greater)		1.0	1.0	1.0
11. Degree of Auxiliary Building Breakthrough or Bypass, Given Preexisting Containment Leakage or Isolation Failure		(i) No Bypass	Likely	Likely	Likely
		(ii) Partial Bypass Caused by Building Damage or Release at Upper Levels of Building	Unlikely	Unlikely	Unlikely
		(iii) Total Bypass	0.0	0.0	0.0
12. Reactor Coolant System Failure Before Vessel Breach			0.0	0.0	0.0
13. Size of Induced RCS Failure	(a) Induced Failure in Hot Leg	(i) Large LOCA (A)	1.0	1.0	1.0
		(ii) Small LOCA (S_2)	0.0	0.0	0.0
		(iii) Other	0.0	0.0	0.0
	(b) Induced Failure in Cold Leg or Steam Generator Tube	(i) Large LOCA (A)	0.0	0.0	0.0
		(ii) Small LOCA (S_2)	1.0	1.0	1.0
		(iii) Other	0.0	0.0	0.0
17. Containment Spray Failure to Actuate After Induced LOCA	(a) Large Induced LOCA and No Gross Preexisting Leakage (Level iv)		0.0	0.0	0.0
	(b) Small Induced LOCA and No Large Preexisting Leakage (Level iii or Greater)		0.0	0.0	[illegible]
	(c) Otherwise		1.0	1.0	1.0
21. Hydrogen Burn Before Vessel Breach	(a) Induced Large LOCA and No Large Preexisting Leakage (Level iii or Greater)		Impossible	Unlikely	Unlikely
	(b) Induced Large LOCA and Level ii Preexisting Leakage		Impossible	Impossible	Unlikely
	(c) Otherwise		Impossible	Impossible	Impossible
22. Containment Failure from Hydrogen Burn Before Vessel Breach			Calculated from Containment Pressure Loading and Capacity, See Tables 2.4 and 2.5.		
23. Auxiliary Building Breakthrough or Bypass Given Containment Failure from Hydrogen Burn Before Vessel Breach		(i) No Bypass	0.0	0.0	0.0
		(ii) Partial Bypass Due to Building Damage or Release at Upper Levels of Building	Unlikely	Remotely Possible	Impossible
		(iii) Total Bypass	Likely	Almost Certain	Certain

Lack of an entry in the column entitled "Branching Options" denotes that the positive path is assumed (i.e., the path corresponding to a "Yes" answer). The appropriate likelihood values for the negative path are the complement of the values given for the positive path.

(Continued)

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TABLE 2.3. EVENT DESCRIPTIONS AND LIKELIHOODS FOR EVENT S_2D_1
(CONT'D)

EVENT	PRIOR EVENTS	BRANCHING OPTIONS	LIKELIHOOD OPTIMISTIC	 CENTRAL	 PESSIMISTIC
25. Containment Spray Failure, Given Hydrogen Burn Before Vessel Breach	(a) Containment Not Failed		Remotely Possible	Remotely Possible	Remotely Possible
	(b) Containment Failed		Unlikely	Unlikely	Likely
27. Mode of Vessel Breach	(a) No Induced Large LOCA	(i) Steam Explosion-Upper Head Failure (α mode)	0.0	0.0001	0.1
		(ii) Steam Explosion-Bottom Head Failure	0.0	0.21	0.4
		(iii) High Pressure Ejection	1.0	0.79	0.5
		(iv) Meltthrough	0.0	0.0	0.0
	(b) Induced Large LOCA	(i) Steam Explosion-Upper Head Failure (α mode)	0.0	0.0001	0.1
		(ii) Steam Explosion-Bottom Head Failure	0.0	0.21	0.4
		(iii) High Pressure Ejection	0.0	0.0	0.0
		(iv) Meltthrough	1.0	0.79	0.5
28. Occurrence of Direct Heating at Vessel Breach	(a) Induced Large LOCA		0.0	0.0	0.0
	(b) Otherwise		0.0	1.0	1.0
29. Occurrence of Hydrogen Burn at Vessel Breach	(a) No Preexisting Large Containment Leakage (Level iii or Greater) and No Earlier Hydrogen Burn		Likely	Likely	Likely
	(b) Large Preexisting Containment Leakage and No Induced Large LOCA and No Earlier Hydrogen Burn		Impossible	Likely	Likely
	(c) Otherwise		0.0	0.0	0.0
30. Containment Failure from Steam Spike, Direct Heating, and/or Hydrogen Burn at Vessel Breach			Calculated from Containment Pressure Loading and Capacity. See Tables 2.4 and 2.5.		
33. Auxiliary Building Breakthrough or Bypass Given Containment Failure at Vessel Breach	(a) Steam Explosion α-mode Failure	(i) No Bypass	0.0	0.0	0.0
		(ii) Partial Bypass	0.0	0.0	0.0
		(iii) Total Bypass	1.0	1.0	1.0
	(b) Other Failure Modes	(i) No Bypass	0.0	0.0	0.0
		(ii) Partial Bypass	Unlikely	Remotely Possible	Impossible
		(iii) Total Bypass	Likely	Almost Certain	Certain
34. Containment Spray Failure after Vessel Breach	(a) Containment not Failed		Remotely Possible	Unlikely	Indeterminate
	(b) Containment Failed, but not α-mode		Unlikely	Unlikely	Indeterminate
	(c) α-mode Failure		1.0	1.0	1.0
35. Oxidation Release	(a) Direct Heating		1.0	1.0	1.0
	(b) Otherwise		0.0	0.0	0.0
43. Significant Core-Concrete Interactions After Vessel Breach	(a) Vessel Failure from Steam Explosion		Remotely Possible	Unlikely	Indeterminate
	(b) Ejection at High Pressure		Remotely Possible	Unlikely	Indeterminate
	(c) Ejection at Intermediate pressure		Unlikely	Likely	Almost Certain
	(d) Ejection at Low Pressure (S_3)		Indeterminate	Likely	Almost Certain
44. Internal Pressure late in the Accident Due to Gradual Pressurization from the Boiloff of Water in Containment.		See Table 2.6			

(Continued)

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TABLE 2.3. EVENT DESCRIPTIONS AND LIKELIHOODS FOR EVENT S_2D_1
(CONT'D)

EVENT	PRIOR EVENTS	BRANCHING OPTIONS	LIKELIHOOD		
			OPTIMISTIC	CENTRAL	PESSIMISTIC
48. Containment Failure Due to Hydrogen Burn or Generation of Steam and Noncondensibles During Core-Concrete Interactions			Calculated from Containment Pressure Loading and Capacity. See Tables 2.4 and 2.5		
49. Containment Failure Mode Late in Accident	(a) Containment Failure Due to Hydrogen Burn	(i) No Containment Failure	0.0	0.0	0.3
		(ii) Containment Leakage	0.0	0.0	0.0
		(iii) Gross Structural Failure	1.0	1.0	1.0
	(b) Late Failure Due to Steam and Non-Condensible Gas Overpressure	(i) No Containment Failure	0.0	0.0	0.0
		(ii) Containment Leakage	Unlikely	Remotely Possible	Impossible
		(iii) Gross Structural Failure	Likely	Almost Certain	Certain
	(c) Otherwise	(i) No Containment Failure	1.0	1.0	1.0
		(ii) Containment Leakage	0.0	0.0	0.0
		(iii) Gross Structural Failure	0.3	0.0	0.0
50. Auxiliary Building Breakthrough or Bypass, Given Late Containment Failure	(a) Containment Leakage	(i) No Bypass	Likely	Indeterminate	Unlikely
		(ii) Partial Bypass	Unlikely	Indeterminate	Likely
		(iii) Total Bypass	0.0	0.0	0.0
	(b) Gross Containment Structural Failure	(i) No Bypass	0.0	0.6	0.0
		(ii) Partial Bypass	Unlikely	Remotely Possible	Impossible
		(iii) Total Bypass	Likely	Almost Certain	Certain
53. Late Containment Spray Failure, Given No Earlier Failure	(a) No Containment Failure		Remotely Possible	Unlikely	Indeterminate
	(b) Containment Failure from Late Hydrogen Burn		Unlikely	Unlikely	Indeterminate
54. Vaporization Release	(a) No Containment Sprays and Debris Bed Not Coolable		1.0	1.0	1.0
	(b) Otherwise		0.0	0.0	0.0
55. Late Containment Leakage Due to High Temperature			0.0	0.0	0.0
56. Basemat Meltthrough Before Containment Overpressurization	(a) Containment Spray Operable at Some Time During Accident		Unlikely	Unlikely	Remotely Possible
	(b) No Containment Spray		Indeterminate	Indeterminate	Unlikely
57. Containment Depressurization, Given Basemat Meltthrough	(a) Containment Spray Operable at Some Time During Accident		Likely	Unlikely	Remotely Possible
	(b) No Containment Spray		Likely	Indeterminate	Unlikely
58. Mode of Very Late Containment Failure Given no Prior Containment Failure	(a) Containment Sprays Operable Late but Debris Bed not Coolable	(i) No Containment Failure	Likely	Indeterminate	Unlikely
		(ii) Basemat Meltthrough Only	Unlikely	Indeterminate	Likely
		(iii) Containment Leakage due to Pressurization During Core-Concrete Interaction	0.0	0.0	0.0
		(iv) Gross Containment Structural Failure Due to Pressurization During Core-Concrete Interaction	0.0	0.0	0.0

Continued

TABLE 2.3. EVENT DESCRIPTIONS AND LIKELIHOODS FOR EVENT S_2D;
(CONT'D)

EVENT	PRIOR EVENTS	BRANCHING OPTIONS	LIKELIHOOD OPTIMISTIC	CENTRAL	PESSIMISTIC
	(b) Containment Sprays not Operable Late, but no Basemat Meltthrough	(i) No Failure	Unlikely	Impossible	Impossible
		(ii) Basemat Meltthrough Only	0.0	0.0	0.0
		(iii) Leakage Due to Pressurization during Core-Concrete	Likely	Unlikely	Impossible
		(iv) Structural Failure due to Pressurization during Core-Concrete	Unlikely	Likely	Certain
	(c) Containment Sprays not Operable Late, Basemat Meltthrough Occurs, but no Repressurization	(i) No Failure	0.0	0.0	0.0
		(ii) Basemat Meltthrough Only	Unlikely	Impossible	Impossible
		(iii) Leakage due to Pressurization during Core-Concrete	Likely	Unlikely	Impossible
		(iv) Structural Failure due to Pressurization during Core-Concrete	Unlikely	Likely	Certain
	(d) Same as (c), but Containment Depressurizes Following Basemat Meltthrough	(i), (iii), (iv)	0.0	0.0	0.0
		(ii) Basemat Meltthrough Only	1.0	1.0	1.0
[illegible]. Auxiliary Building Breakthrough or Bypass, Given Very Late Containment Failure	(a) Containment Leakage	(i) No Bypass	Likely	Indeterminate	Unlikely
		(ii) Partial Bypass	Unlikely	Indeterminate	Likely
		(iii) Total Bypass	0.0	0.0	0.0
	(b) Gross Containment Structural Failure	(i) No Bypass	0.0	0.0	0.0
		(ii) Partial Bypass	Unlikely	Remotely Possible	Impossible
		(iii) Total Bypass	Likely	Almost Certain	Certain

TABLE 3.4. CONTAINMENT LOADINGS FOR SURRY S$_2$D

SOURCE OF PRESSURE	PRIOR EVENTS	PRESSURES (PSIG) OPTIMISTIC	CENTRAL	PESSIMISTIC
(1) Containment pressure before vessel breach	(a) No large preexisting containment leakage and no sprays	25	25	25
	(b) No large preexisting leakage and sprays operable	5	5	5
	(c) Large preexisting leakage (level iii) and no sprays	5	5	5
	(d) Large preexisting leakage and sprays operable	0	0	0
(2) Containment pressure increment from a hydrogen burn before vessel breach, given containment sprays operating	(a) No large preexisting containment leakage and low RCS pressure	0	25	50
	(b) Large preexisting containment leakage and low RCS pressure	0	0	25
	(c) Otherwise	0	0	0
(3) Total containment pressure following early hydrogen burn		Sum of pressures in (1) and (2)		
(4) Containment pressure increment from reactor coolant system blowdown at vessel breach	(a) High RCS pressure (S$_2$D LOCA with no induced RCS failure)	15	15	15
	(b) Intermediate RCS pressure	7	7	7
	(c) Low RCS pressure	0	0	0
(5) Containment pressure increment from steam spike at vessel breach	(a) High RCS pressure (accumulator discharge at vessel breach)	11	15	26
	(b) Intermediate or low RCS pressure (early accumulator discharge) and sprays operating	11	15	26
	(c) Intermediate or low RCS pressure and sprays never on	0	2	4
(6) Containment pressure increment from combination of steam spike and direct heating at vessel breach	(a) High RCS pressure or steam explosion failing upper head	11	44	104
	(b) Intermediate RCS pressure, no steam explosion failing upper head, and containment sprays operating	11	32	65
	(c) Same as (b), but containment sprays never on	22	0	34
	(d) Low RCS pressure and no steam explosion failing upper head	Same pressures as in (5b), (5c)		
(7) Containment pressure increment from hydrogen burn at vessel breach, given containment sprays operating	(a) No large preexisting containment leakage and no prior burn	25	35	70
	(b) Large LOCA, large preexisting leakage, and no prior burn	0	25	55
	(c) Intermediate LOCA, large pre-leakage, and no prior burn	0	0	35
	(d) Small LOCA, large pre-existing leakage, and no prior burn	0	25	65
	(e) Otherwise	0	0	0
(8) Total containment pressure following vessel breach	(a) Steam spike only	Sum of pressures in (1), (4), and (5)		
	(b) Steam spike and direct heating	Sum of pressures in (1), (4), and (6)		
	(c) Steam spike and hydrogen burn	Sum of pressures in (1), (4), (5), and (7)		
	(d) Steam spike, direct heating, and hydrogen burn	Sum of pressures in (1), (4), (6), and (7)		

(Continued)

TABLE 2.4. CONTAINMENT LOADINGS FOR EVENT S_2D_1
(CONT'D)

SOURCE OF PRESSURE	PRIOR EVENTS	PRESSURES (PSIG) OPTIMISTIC	CENTRAL	PESSIMISTIC
(9) Total containment pressure late in accident (10 hrs.)	(a) Sprays never operate and debris bed is not coolable	70	70	70
	(b) Sprays injection but no operation thereafter and debris bed is coolable	145	145	145
	(c) Sprays operate early or late but not both	5	15	25
	(d) Sprays never operate, high natural condensation	15	25	45
	(e) Sprays operate early and late, debris bed is coolable	5	5	5
(10) Containment pressure increment from a late hydrogen burn, given containment sprays operating at same time	(a) Debris bed is not coolable or is coolable as a result of dispersal associated with direct heating, no prior burn, or recovered very late	55	70	110
	(b) Debris bed is not coolable or is coolable as a result of dispersal associated with direct heating, no prior burn, or recovered by 6 hours	55	55	70
	(c) Debris is coolable in reactor cavity, no direct heating, no prior burn	55	55	70
	(d) Prior burn	0	0	0
(11) Total containment pressure after late hydrogen burn		Sum of pressures in (9) and (10)		

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TABLE 3.2. SURRY CONTAINMENT CAPACITY ESTIMATES

(a) Leakage Area Versus Pressure

PRESSURE (psig)	LEAK AREA (in^2) OPTIMISTIC	CENTRAL	PESSIMISTIC	
0	.004	.004	.004	
45	.004	.004	.004	(linear
119	.004	.004	.36	variation)

(b) Structural Failure Pressure

	PRESSURE (psig) OPTIMISTIC	CENTRAL	PESSIMISTIC
Mean Structural Failure Pressure	119	119	85
Standard Deviation	2.5	15	15

Table 2.6 Basis for Pressure Estimates for Concurrent Direct Heating/Steam Spike

		Optimistic	Central	Pessimistic
(1)	Percent of Core Melt Ejected at the Time of Vessel Breach	50%	75%	100%
(2)	Percent of Amount in (1) Quenched Thermally in water	80%	75%	50%
(3)	Percent of Amount in (2) which Reacts with Steam	0%	30%	30%
(4)	Percent of Amount in (1) Quenched Thermally in Atmosphere	2%	25%	50%
(5)	Percent of Amount in (4) which Reacts with Steam	0%	50%	0%
(6)	Percent of Amount in (4) which Reacts with Oxygen	0%	0%	50%
(7)	Pressure Increment	11 psi	44 psi	104 psi

TABLE 2.7. ALTERNATIVE ASSIGNMENT OF VALUES TO VERBAL DESCRIPTORS

VERBAL DESCRIPTOR	LIKELIHOOD			
	ALT. 1 (BASE CASE)	ALT. 2	ALT. 3	ALT. 4
Certain or Almost Certain	1.0	1.0	1.0	1.0
Likely	0.9	0.9	0.9	0.9
Indeterminate	0.5	0.5	0.5	0.5
Unlikely	0.1	0.01	0.01	0.1
Remotely Possible	0.001	0.001	0.0001	0.01
Impossible	0	0	0	0

Table 2-8

IDENTIFICATION OF PLANT-DAMAGE STATES

Designator	Description
V(WET)	LOCA outside containment, with the break location submerged.
V(DRY)	LOCA outside containment, with the break location not submerged.
AYYB	LOCA leading to low pressure in the RCS prior to vessel breach, with RWST inventory discharged to containment; containment heat removal, spray injection, and spray recirculation are all available.
AYNI	LOCA leading to low pressure in the RCS prior to vessel breach, with RWST inventory discharged to containment; containment spray injection is available, but containment heat removal and recirculation are not functioning.
AYYR	LOCA leading to low pressure in the RCS prior to vessel breach, with RWST inventory discharged to containment; containment spray injection has failed, but containment heat removal and recirculation are available.
AYNB	LOCA leading to low pressure in the RCS, with RWST inventory discharged to containment; containment spray injection and recirculation are successful, but containment heat removal is not available. Note that this particular plant damage state implies core melt due to the failure of containment heat removal, such that long-term overpressurization of containment prior to core melt would be expected.
AYNN	LOCA leading to low pressure in the RCS prior to vessel breach, with RWST inventory discharged to containment; the containment spray systems are not available. Note that this implies that there may be only limited water available in the reactor cavity.
S_2YYB	Small LOCA with intermediate pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment heat removal, spray injection, and spray recirculation are all available.

Table 2-8

IDENTIFICATION OF PLANT-DAMAGE STATES
(Continued)

Designator	Description
S_2YNI	Small LOCA with intermediate pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment spray injection is available, but containment heat removal and recirculation are not functioning.
S_2YYR	Small LOCA with intermediate pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment spray injection has failed, but containment heat removal and recirculation are available.
S_2YNN	Small LOCA with intermediate pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; the containment spray systems are not available. Note that this implies that there may be only limited water available in the reactor cavity.
S_2NNN	Small LOCA with intermediate pressure in the RCS prior to vessel breach; no RWST inventory is discharged to containment and the containment spray systems are not available. Note that this implies that there will be very limited water available in the reactor cavity.
S_3YYB	Very small LOCA with high pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment heat removal, spray injection, and spray recirculation are all available.
S_3YNI	Very small LOCA with high pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment spray injection is available, but containment heat removal and recirculation are not functioning.
S_3YYR	Very small LOCA with high pressure in the RCS prior to vessel breach, and RWST inventory discharged to containment; containment spray injection has failed, but spray recirculation and containment heat removal are available.
S_3YNN	Very small LOCA with high pressure in the RCS prior to vessel breach, and RWST inventory discharged to containment; the containment spray

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Table 2-8

IDENTIFICATION OF PLANT-DAMAGE STATES
(Continued)

Designator	Description
	systems are not available. Note that this implies that there may be only limited water available in the reactor cavity.
S_3NNN	Very small LOCA with high pressure in the RCS prior to vessel breach; no RWST inventory is discharged to containment and the containment spray systems are not available. Note that this implies that there will be very limited water available in the reactor cavity.
TYYB	Intact RCS prior to vessel breach, with RWST inventory discharged to containment; containment heat removal, spray injection, and spray recirculation are all available.
TYNI	Intact RCS prior to vessel breach, with RWST inventory discharged to containment; containment spray injection is available, but containment heat removal and recirculation are not functioning.
TYYR	Intact RCS prior to vessel breach, with RWST inventory discharged to containment spray injection has failed, but containment heat removal and recirculation are available.
TYNN	Intact RCS prior to vessel breach, with RWST inventory discharged to containment; the containment spray systems are not available. Note that this implies that there may be only limited water available in the reactor cavity.
TNNN	Intact RCS prior to vessel breach, with no RWST inventory discharged to containment and the containment spray systems not available. Note that this implies that there will be very limited water available in the reactor cavity.

Table 3.1

RESULTS FOR SURRY S_2D_1

(Small Pipe Break LOCA with Failure of Emergency Core Cooling Injection)

I. SEQUENCE FREQUENCY

	OPT	CENTRAL	PESS.
ASEP Baseline Value		8×10^{-7}	

II. CONTAINMENT FAILURE MODE PROBABILITIES

	OPT.	CENTRAL		PESS.	
		CASE 1*	CASE 2*	CASE 1*	CASE 2*
No Containment Failure	.90	.51	.51	.01	.007
Basemat Meltthrough Only	.01	.30	.30	.01	.007
Late Overpressurization (Pressure Relief)	.08	.02	.02	--	--
Late Overpressurization (Rupture)	.01	.17	.17	.10	.07
Late Hydrogen Burn	--	--	--	.03	.03
Early Steam Spike and/or Vessel Depressurization	--	--	--	--	--
Early Steam Spike/Depres. + Hydrogen Burn	--	--	--	.84	.34
Early Steam Spike/Depres. + Direct Heating*	--	--	--	--	.45
In-Vessel Steam Explosion (Missile Breach)	--	--	--	--	.1
Large Isolation Failure or Preexisting Leak	--	.002	.002	.002	.002
	1.00	1.00	1.00	1.00	1.00
Fraction of Above Affected by:					
(a) Preexisting Small Containment Leak**	.01	.03	.03	.05	.05
(b) Induced Small Steam Generator Tube Leak**	--	--	--	--	--

III. PRINCIPAL CONTAINMENT PATHWAYS

General: Initial break is likely to occur in a cold leg. Additional RCS failures comparable in size to the initial break are not induced prior to vessel breach. Principal mode of vessel breach is high pressure ejection. An in-vessel steam explosion causing failure of the bottom head but not containment failure occurs with moderate frequency in the central and pessimistic walkthroughs. A coolable ex-vessel debris bed generally does not occur in the central and pessimistic walkthroughs; however, vaporization releases are scrubbed by an overlying water layer. Oxidation releases occur in the central and pessimistic walkthroughs.

	BMI-2104 CALCULATION
(1) No Containment Failure. Containment sprays survive throughout the accident.	Yes, without steam explosion.
(2) Basemat Meltthrough. Containment sprays survive throughout the accident.	No, but source term is similar to (1).
(3) Late Overpressurization (Rupture). Containment sprays fail either after vessel breach or after a late hydrogen burn that does not fail containment. Auxiliary building is generally bypassed.	No.
(4) Late Hydrogen Burn. Containment sprays survive after vessel breach but may fail after containment failure. Auxiliary building is generally bypassed.	No.
(5) Early Steam Spike/Depressurization/Hydrogen Burn/Direct Heating. Moderate probability of containment spray failure after containment failure. Auxiliary building is generally bypassed.	Yes, without steam explosion or direct heating.
(6) Large Isolation Failure or Preexisting Leak. Moderate probability that containment sprays do not actuate because containment pressure setpoint is not reached (pessimistic walkthrough). Significant deposition in auxiliary building is likely.	No.

* Case 2 for central and pessimistic walkthroughs includes the effects of in-vessel steam explosions and ex-vessel direct heating. Case 1 does not include these effects. Direct heating includes hydrogen burning if the atmosphere is flammable. See text for a discussion of limitations associated with the results for steam explosions and direct heating.

** Small containment leaks include those producing leakage greater than containment design but not large enough to preclude gradual overpressurization from steam and/or noncondensibles. Likewise, small steam generator tube leaks include those producing primary-to-secondary leakage greater than design but not large enough to depressurize the primary system below the accumulator setpoint before vessel breach.

Table 1.2

RESULTS FOR SURRY T$_1$LDCF$_1$
(Station Blackout, Including Loss of Auxiliary Feedwater)

I. SEQUENCE FREQUENCY

	OPT.	CENTRAL	PESS.
ASEP Baseline Value		2×10^{-6}	

II. CONTAINMENT FAILURE MODE PROBABILITIES

	OPT.	CENTRAL		PESS.	
		CASE 1*	CASE 2*	CASE 1*	CASE 2*
No Containment Failure	.89	.63	.62	.02	.01
Basemat Meltthrough Only	.02	.20	.20	.002	--
Late Overpressurization (Pressure Relief)	.08	.016	.016	--	--
Late Overpressurization (Rupture)	.01	.15	.15	.26	.12
Late Hydrogen Burn	--	.01	.01	.63	.31
Early Steam Spike and/or Vessel Depressurization	--	--	--	.08	.03
Early Steam Spike/Depres. + Hydrogen Burn	--	--	--	--	--
Early Steam Spike/Depres. + Direct Heating*	--	--	.004	--	.41
In-Vessel Steam Explosion (Missile Breach)	--	--	--	--	.10
Large Isolation Failure or Preexisting Leak	--	.002	.002	.002	.002
	1.00	1.00	1.00	1.00	1.00
Fraction of Above Affected by:					
(a) Preexisting Small Containment Leak**	.01	.03	.03	.05	.05
(b) Induced Small Steam Generator Tube Leak**	--	.001	.001	.10	.10

III. PRINCIPAL CONTAINMENT PATHWAYS

General: An induced failure of the hot leg or induced seal LOCA usually occurs. In the pessimistic walkthrough, small SGTRs are possible. Vessel failure modes are pressure ejection or meltthrough accompanying induced hot leg ruptures, or in-vessel steam explosions failing the bottom head in the central and pessimistic walkthroughs. Vaporization release almost always occurs and oxidation release almost always occurs in the central and pessimistic walkthroughs.

	BMI-2104 CALCULATION
(1) No Containment Failure: Sprays recovered late; a permanently coolable debris bed often forms.	No, but consequences similar to below.
(2) Basemat Meltthrough: Sprays recovered in approximately half of the cases; a permanently coolable debris bed is not formed.	Yes, (no steam explosions, induced RCS failures, or direct heating).
(3) Late Overpressurization: Sprays either do not recover or are failed by a later hydrogen burn that does not fail containment. A debris bed may be temporarily cooled but dries out after spray failure. The auxiliary building is bypassed.	No.
(4) Late Hydrogen Burn: Sprays are recovered before the burn, but may fail again after containment rupture. Auxiliary building bypassed.	No.
(5) Steam Spike/Depressurization/Direct Heating: Sprays never operate prior to containment failure. Moderate probability of later recovery. The auxiliary building is bypassed.	Yes, (no steam explosions, direct heating, or induced RCS failures).
(6) Isolation Failure: Either no gross containment failure occurs or there is a direct heating failure at vessel breach. Sprays may or may not recover. The isolation failure is usually mitigated by the auxiliary building, but later gross containment failures bypass the auxiliary building.	No.

* Case 2 for central and pessimistic walkthroughs includes the effects of in-vessel steam explosions and ex-vessel direct heating. Case 1 does not include these effects. Direct heating includes hydrogen burning if the atmosphere is flammable. See text for a discussion of limitations associated with the results for steam explosions and direct heating.

** Small containment leaks include those producing leakage greater than containment design but not large enough to preclude gradual overpressurization from steam and/or noncondensibles. Likewise, small steam generator tube leaks include those producing primary-to-secondary leakage greater than design but not large enough to depressurize the primary system below the accumulator setpoint before vessel breach.

Table 3.3

RESULTS FOR SURRY ACD_6F_1
(Large Pipe Break LOCA with Failure of All AC Power)

I. SEQUENCE FREQUENCY

	OPT.	CENTRAL	PESS.
ASEP Baseline Value		1×10^{-9}	

II. CONTAINMENT FAILURE MODE PROBABILITIES

	OPT.	CENTRAL		PESS.	
		CASE 1*	CASE 2*	CASE 1*	CASE 2*
No Containment Failure	.82	.47	.47	.02	.01
Basemat Meltthrough Only	.10	.35	.35	.003	.002
Late Overpressurization (Pressure Relief)	.07	.02	.15	--	--
Late Overpressurization (Rupture)	.009	.15	.02	.27	.24
Late Hydrogen Burn	--	.01	.01	.71	.65
Early Steam Spike and/or Vessel Depressurization	--	--	--	--	--
Early Steam Spike/Depres. + Hydrogen Burn	--	--	--	--	--
Early Steam Spike/Depres. + Direct Heating*	--	--	--	--	--
In-Vessel Steam Explosion (Missile Breach)	--	--	--	--	.1
Large Isolation Failure or Preexisting Leak	--	.002	.002	.002	.002
	1.00	1.00	1.00	1.00	1.00
Fraction of Above Affected by:					
(a) Preexisting Small Containment Leak**	.01	.03	.03	.03	.05
(b) Induced Small Steam Generator Tube Leak**	--	--	--	--	--

III. PRINCIPAL CONTAINMENT PATHWAYS

General: Initial break occurs with comparable frequency in the hot legs or cold legs. Additional RCS failures are not induced. The principal mode of vessel failure is a low pressure meltthrough; in-vessel steam explosions fail the bottom head (but do not threaten containment) with moderate frequency in central and pessimistic walkthroughs. Permanently coolable debris beds are not generally formed. Vaporization releases occur in all walkthroughs and oxidation releases occur with moderate frequency in central and pessimistic walkthroughs.

	BMI-2104 CALCULATION
(1) No Containment Failure: Containment sprays are recovered late in the accident.	No, but consequences similar to basemat meltthrough.
(2) Basemat Meltthrough: Containment sprays are not generally recovered.	Yes, (no steam explosions).
(3) Late Overpressurization: Containment sprays are inoperative throughout the accident. The auxiliary building is generally bypassed.	No, but consequences should be similar to late hydrogen burn.
(4) Late Hydrogen Burn: Containment sprays are recovered prior to the hydrogen burn, and may fail after containment failure. The auxiliary building is generally bypassed.	Yes, without in-vessel steam explosions.
(5) Steam Spike/Depressurization: The sprays never operate prior to containment failure. There is moderate probability of later spray recovery. The auxiliary building is bypassed.	No.
(6) Isolation Failure: No gross containment failure occurs. There is moderate probability of later recovery of containment sprays.	Yes, for isolation failure with no gross containment failure, and no in-vessel steam explosions.

* Case 2 for central and pessimistic walkthroughs includes the effects of in-vessel steam explosions and ex-vessel direct heating. Case 1 does not include these effects. Direct heating includes hydrogen burning if the atmosphere is flammable. See text for a discussion of limitations associated with the results for steam explosions and direct heating.

** Small containment leaks include those producing leakage greater than containment design but not large enough to preclude gradual overpressurization from steam and/or noncondensibles. Likewise, small steam generator tube leaks include those producing primary-to-secondary leakage greater than design but not large enough to depressurize the primary system below the accumulator setpoint before vessel breach.

TABLE 3.4 CONTAINMENT RELEASE MODE - PLANT DAMAGE STATE MATRIX OF RESULTS FOR SURRY OPTIMISTIC WALKTHROUGH
(TABLE OF CONDITIONAL RELEASE MODE PROBABILITIES)

	PLANT DAMAGE STATES AND CORRESPONDING ASEP BASELINE FREQUENCIES									
	THHN	TYYB	S_3HHN	S_3YYB	S_2HHN	S_2YYB	AYHN	AYHH	AYYB	V
CONTAINMENT RELEASE MODES	(4.5×10^{-6})	(3.0×10^{-6})	(1.5×10^{-6})	(1.5×10^{-6})	(3.4×10^{-7})	(9.3×10^{-7})	(4.2×10^{-9})	(4.9×10^{-6})	(2.2×10^{-6})	(8.7×10^{-7})
1. No Containment Failure	.89	.90	.89	.90	.90	.90	.05	--	.86	--
2. Basemat Meltthrough Only with Containment Sprays Operable	.02	.01	.02	.01	.009	.009	--	--	.05	--
3. Basemat Meltthrough Only with Containment Sprays Inoperable	.002	.001	.002	.001	.001	.001	.46	--	.005	--
4. Late Overpressurization (Pressure Relief)	.08	.08	.08	.08	.08	.08	.44	--	.08	--
5. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Operating through the Time of Core-Concrete Interaction	.008	.009	.008	.009	.009	.009	--	--	.005	--
6. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Not Operating through the Time of Core-Concrete Interaction	.002	.001	.002	.001	.001	.001	.06	--	.005	--
7. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Continuing to Operate through the Time of Core-Concrete Interactions.	--	--	--	--	--	--	--	--	--	--
8. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Not Continuing to Operate through the Time of Core-Concrete Interactions.	--	--	--	--	--	--	--	--	--	--
9. Same as No. 7, but RCS Not at High Pressure	--	--	--	--	--	--	--	--	--	--
10. Same as No. 8, but RCS Not at High Pressure	--	--	--	--	--	--	--	--	--	--
11. Large Containment Isolation Failure (4.0 Sq. In.) with Sprays Operating	--	--	--	--	--	--	--	--	--	--
12. Large Containment Isolation Failure (4.0 Sq. In.) with Sprays Not Operating	--	--	--	--	--	--	--	--	--	--
13. Containment Failure Before Core Melt with Sprays Continuing to Operate	--	--	--	--	--	--	--	.90	--	--
14. Containment Failure Before Core Melt with Sprays Subsequently Inoperable.	--	--	--	--	--	--	--	.10	--	--
15. Containment Bypass (V Sequence) with Point of Release Submerged	--	--	--	--	--	--	--	--	--	1.0
16. Containment Bypass (V Sequence) with Point of Release Not Submerged	--	--	--	--	--	--	--	--	--	--

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TABLE 3.5 CONTAINMENT RELEASE MODE - PLANT DAMAGE STATE MATRIX OF RESULTS FOR SURRY CENTRAL WALKTHROUGH WITHOUT CVSR OR DIRECT HEATING (TABLE OF CONDITIONAL RELEASE MODE PROBABILITIES)

	PLANT DAMAGE STATES AND CORRESPONDING ASEP BASELINE FREQUENCIES									
CONTAINMENT RELEASE MODES	TMLU ($4.5x10^{-6}$)	YYYB ($3.0x10^{-6}$)	S_3HHU ($1.5x10^{-6}$)	S_3YYD ($1.5x10^{-6}$)	S_2HHU ($3.4x10^{-7}$)	S_2YYD ($9.3x10^{-7}$)	AYHU ($4.2x10^{-9}$)	AYHD ($4.9x10^{-6}$)	AY/D ($2.2x10^{-6}$)	V ($6.7x10^{-7}$)
1. No Containment Failure	.62	.64	.62	.64	.51	.51	--	--	.51	--
2. Basemat Meltthrough Only with Containment Sprays Operable	.17	.17	.17	.17	.29	.30	--	--	.30	--
3. Basemat Meltthrough Only with Containment Sprays Inoperable	.003	.001	.002	.001	.02	.003	.20	--	.001	--
4. Late Overpressurization (Pressure Relief)	.02	.02	.02	.02	.02	.02	.06	--	.02	--
5. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Operating through the Time of Core-Concrete Interaction	.09	.10	.09	.10	.05	.05	.005	--	.05	--
6. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Not Operating through the Time of Core-Concrete Interaction	.07	.07	.07	.07	.11	.12	.73	--	.12	--
7. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Continuing to Operate through the Time of Core-Concrete Interactions.	.003	--	.003	--	--	--	--	--	--	--
8. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Not Continuing to Operate through the Time of Core-Concrete Interactions.	.001	--	.001	--	--	--	--	--	--	--
9. Same as No. 7, but RCS Not at High Pressure	--	--	--	--	--	--	--	--	--	--
10. Same as No. 8, but RCS Not at High Pressure	--	--	--	--	--	--	--	--	--	--
11. Large Containment Isolation Failure (4.0 Sq. In.) with Sprays Operating	.002	.002	.002	.002	.002	.002	--	--	.002	--
12. Large Containment Isolation Failure (4.0 Sq. In.) with Sprays Not Operating	--	--	--	--	--	--	.002	--	--	--
13. Containment Failure Before Core Melt with Sprays Continuing to Operate	--	--	--	--	--	--	--	.50	--	--
14. Containment Failure Before Core Melt with Sprays Subsequently Inoperable.	--	--	--	--	--	--	--	.50	--	--
15. Containment Bypass (V Sequence) with Point of Release Submerged	--	--	--	--	--	--	--	--	--	.75
16. Containment Bypass (V Sequence) with Point of Release Not Submerged	--	--	--	--	--	--	--	--	--	.25

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TABLE 3.6 CONTAINMENT RELEASE MODE - PLANT DAMAGE STATE MATRIX OF RESULTS FOR SURRY PESSIMISTIC WALKTHROUGH WITHOUT IVSE OR DIRECT HEATING
(TABLE OF CONDITIONAL RELEASE MODE PROBABILITIES)

	PLANT DAMAGE STATES AND CORRESPONDING ASEP BASELINE FREQUENCIES									
	TRRR	TYYB	S_3RRR	S_3YYB	S_2RR-	S_2YYB	ATRR	ATRB	ATYB	V
CONTAINMENT RELEASE MODES	($4.5x10^{-6}$)	($3.0x10^{-6}$)	($1.5x10^{-6}$)	($1.5x10^{-6}$)	($3.4x10^{-7}$)	($9.3x10^{-7}$)	($4.2x10^{-9}$)	($4.9x10^{-6}$)	($2.2x10^{-6}$)	($8.7x10^{-7}$)
1. No Containment Failure	.03	.02	.03	.02	.02	.01	--	--	.02	--
2. Basemat Meltthrough Only with Containment Sprays Operable	--	.009	--	.009	--	.01	--	--	.04	--
3. Basemat Meltthrough Only with Containment Sprays Inoperable	.002	--	.002	--	.002	--	.003	--	--	--
4. Late Overpressurization (Pressure Relief)	--	--	--	--	--	--	--	--	--	--
5. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Operating through the Time of Core-Concrete Interaction	.39	.08	.39	.08	.34	.04	--	--	.07	--
6. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Not Operating through the Time of Core-Concrete Interaction	.49	.10	.49	.10	.62	.09	.99	--	.17	--
7. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Continuing to Operate through the Time of Core-Concrete Interactions.	.01	.35	.01	.35	--	--	--	--	--	--
8. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Not Continuing to Operate through the Time of Core-Concrete Interactions.	.07	.35	.07	.35	--	--	--	--	--	--
9. Same as No. 7, but RCS Not at High Pressure	--	.04	--	.04	.004	.42	--	--	.25	--
10. Same as No. 8, but RCS Not at High Pressure	.001	.04	.001	.04	.01	.42	--	--	.35	--
11. Large Containment Isolation Failure (>4.0 Sq. In.) with Sprays Operating	.001	--	.001	--	.001	--	--	--	.001	--
12. Large Containment Isolation Failure (>4.0 Sq. In.) with Sprays Not Operating	.001	--	.001	--	.001	--	.002	--	.001	--
13. Containment Failure Before Core Melt with Sprays Continuing to Operate	--	--	--	--	--	--	--	.10	--	--
14. Containment Failure Before Core Melt with Sprays Subsequently Inoperable.	--	--	--	--	--	--	--	.90	--	--
15. Containment Bypass (V Sequence) with Point of Release Submerged	--	--	--	--	--	--	--	--	--	.50
16. Containment Bypass (V Sequence) with Point of Release Not Submerged	--	--	--	--	--	--	--	--	--	.50

TABLE 3.7 CONTAINMENT RELEASE MODE - PLANT DAMAGE STATE MATRIX OF RESULTS FOR SURRY CENTRAL WALKTHROUGH WITH IVSE AND DIRECT HEATING
(TABLE OF CONDITIONAL RELEASE MODE PROBABILITIES)

	PLANT DAMAGE STATES AND CORRESPONDING ASEP BASELINE FREQUENCIES									
	TRRR	TYYB	S_3RRR	S_3YYB	S_2RRR	S_2YYB	AYRR	AYYY	AYYB	V
CONTAINMENT RELEASE MODES	(4.5×10^{-6})	(3.0×10^{-6})	(1.5×10^{-6})	(1.5×10^{-6})	(3.4×10^{-7})	(9.3×10^{-7})	(4.2×10^{-9})	(4.9×10^{-6})	(2.2×10^{-6})	(8.7×10^{-7})
1. No Containment Failure	.62	.64	.62	.64	.51	.51	--	--	.51	--
2. Basemat Meltthrough Only with Containment Sprays Operable	.17	.17	.17	.17	.29	.30	--	--	.30	--
3. Basemat Meltthrough Only with Containment Sprays Inoperable	.025	.001	.025	.001	.025	.001	.2	--	.001	--
4. Late Overpressurization (Pressure Relief)	.016	.019	.016	.019	.016	.02	.06	--	.019	--
5. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Operating through the Time of Core-Concrete Interaction	.09	.10	.09	.10	.046	.046	.005	--	.046	--
6. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Not Operating through the Time of Core-Concrete Interaction	.066	.07	.066	.07	.11	.12	.73	--	.12	--
7. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Continuing to Operate through the Time of Core-Concrete Interactions.	.003	.001	.003	.001	--	--	--	--	--	--
8. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Not Continuing to Operate through the Time of Core-Concrete Interactions.	.001	--	.001	--	--	--	--	--	--	--
9. Same as No. 7, but RCS Not at High Pressure	--	--	--	--	--	--	--	--	--	--
10. Same as No. 8, but RCS Not at High Pressure	--	--	--	--	--	--	--	--	--	--
11. Large Containment Isolation Failure (4.0 Sq. In.) with Sprays Operating	.002	.002	.002	.002	.002	.002	--	--	.002	--
12. Large Containment Isolation Failure (4.0 Sq. In.) with Sprays Not Operating	--	--	--	--	--	--	.002	--	--	--
13. Containment Failure Before Core Melt with Sprays Continuing to Operate	--	--	--	--	--	--	--	.90	--	--
14. Containment Failure Before Core Melt with Sprays Subsequently Inoperable.	--	--	--	--	--	--	--	.10	--	--
15. Containment Bypass (V Sequence) with Point of Release Submerged	--	--	--	--	--	--	--	--	--	.75
16. Containment Bypass (V Sequence) with Point of Release Not Submerged	--	--	--	--	--	--	--	--	--	.25

TABLE 3.8 CONTAINMENT RELEASE MODE - PLANT DAMAGE STATE MATRIX OF RESULTS FOR SURRY PESSIMISTIC WALKTHROUGH WITH IVSE OR DIRECT HEATING
(TABLE OF CONDITIONAL RELEASE MODE PROBABILITIES)

	PLANT DAMAGE STATES AND CORRESPONDING ASEP BASELINE FREQUENCIES									
CONTAINMENT RELEASE MODES	TNNB (4.5×10^{-6})	TYYB (3.0×10^{-6})	S_3NNB (1.5×10^{-6})	S_3YYB (1.5×10^{-6})	S_2NNB (3.4×10^{-7})	S_2YYB (9.3×10^{-7})	AYNN (4.2×10^{-9})	AYNB (4.9×10^{-6})	AYYB (2.2×10^{-6})	V (8.7×10^{-7})
1. No Containment Failure	.01	.006	.01	.006	.01	.007	--	--	.02	--
2. Basement Meltthrough Only with Containment Sprays Operable	--	.003	--	.003	--	.007	--	--	.04	--
3. Basement Meltthrough Only with Containment Sprays Inoperable	.001	--	.001	--	.002	--	.003	--	--	--
4. Late Overpressurization (Pressure Relief)	--	--	--	--	--	--	--	--	--	--
5. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Operating through the Time of Core-Concrete Interaction	.19	.04	.19	.04	.27	.04	--	--	.06	--
6. Late Hydrogen Burn or Overpressurization (Rupture) with Containment Sprays Not Operating through the Time of Core-Concrete Interaction	.25	.03	.25	.03	.40	.06	.90	--	.16	--
7. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Continuing to Operate through the Time of Core-Concrete Interactions.	.05	.37	.05	.37	--	--	--	--	--	--
8. Early Rupture (Before or At Vessel Breach) with RCS at High Pressure and Containment Sprays Not Continuing to Operate through the Time of Core-Concrete Interactions.	.46	.46	.46	.46	--	--	--	--	--	--
9. Same as No. 7, but RCS Not at High Pressure	--	.04	--	.04	.004	.39	--	--	.31	--
10. Same as No. 8, but RCS Not at High Pressure	.03	.05	.03	.05	.24	.49	.10	--	.41	--
11. Large Containment Isolation Failure (>4.0 Sq. In.) with Sprays Operating	.001	--	.001	--	.001	--	--	--	.001	--
12. Large Containment Isolation Failure (>4.0 Sq. In.) with Sprays Not Operating	--	--	--	--	.001	--	.002	--	.001	--
13. Containment Failure Before Core Melt with Sprays Continuing to Operate	--	--	--	--	--	--	--	.10	--	--
14. Containment Failure Before Core Melt with Sprays Subsequently Inoperable.	--	--	--	--	--	--	--	.90	--	--
15. Containment Bypass (V Sequence) with Point of Release Submerged	--	--	--	--	--	--	--	--	--	.50
16. Containment Bypass (V Sequence) with Point of Release Not Submerged	--	--	--	--	--	--	--	--	--	.50

TABLE 3.9 SENSITIVITY OF SAMPLE CASE RESULTS
TO ALTERNATIVE ASSIGNMENTS OF NUMERICAL VALUES

	OPTIMISTIC				CENTRAL				PESSIMISTIC			
Unlikely	.1	.01	.01	.1	.1	.01	.01	.1	.1	.01	.01	.1
Remote Poss.	.001	.001	.0001	.01	.001	.001	.0001	.01	.001	.001	.0001	.01
No Failure	.95	.99	.99	.93	.46	.54	.54	45	.006	.007	.007	.006
Meltthrough	.05	.006	.005	.06	.45	.45	.45	.45	.06	.06	.06	.06
Late Overpressure	.001	.001		.01	.09	.01	.01	.09	.03	.02	.02	.03
Late Leak									.01	.01	.01	.01
Late H_2 Burn					.001			.001	.06	.05	.05	.06
Early Leak									.03	.03	.03	.03
Steam Spike												
Early H_2 Burn									.04	.04	.04	.04
SS + H_2 Burn									.77	.77	.77	.77
Isol. Failure					.002	.002	.002	.002	.002	.002	.002	.002

APPENDIX A
SAMPLE EVENT TREE PROBLEM

A sample event tree problem has been constructed to facilitate the discussion of how input for the event tree program is structured. Before discussing this sample problem, some of the capabilities of the program are discussed.

The event tree program was written to do the bookkeeping of very large event trees that were necessary to properly address problems in the Severe Accident Risk Reduction Program (SARRP). The event trees developed in SARRP typically involved at least 50 "top questions" or "nodes". This in itself established a need for an automated bookkeeping procedure for the trees. In addition, without making very conservative assumptions (something we were to avoid in SARRP) nearly all of the branch point probabilities were dependent upon the occurrence or absence of prior events in the tree -- something very few other past event tree analyses have allowed for. Not only were most of the branch point probabilities dependent upon the path taken in the event tree up to that point, some of the probabilities needed to be calculated internally. That is, the user did not know a priori what the probability would be. This was most frequently the case for the probability of containment failure. In these instances, pressure loads were compared to estimates of a containment failure pressure distribution to obtain an estimate of containment failure probability. Keeping these points in mind, several key features of the program will be discussed.

As mentioned above, most of the questions involve user supplied branch point probabilities. However some questions utilize the capability of the program to internally calculate the branch point probability. The way this is performed is certain "parameters" which have had values specified at previous nodes are added together and compared to "reference parameters" which have a value specified at the current node. Take for example the probability of containment failure due to an early hydrogen burn. This is dependent upon the baseline pressure in containment prior to the burn, the probability of a hydrogen burn occurring, the pressure rise due to the burn, and containment failure pressure. Typically the value of baseline pressure and pressure rise due to the burn would be supplied at prior nodes as "parameters". The probability of the burn occurring would be input as a branch point probability at an earlier node (most likely the same one that supplied the value of pressure rise due to the burn). Then at the node which addresses early hydrogen burn failures, the program would be instructed to add the values of baseline pressure and hydrogen-burn pressure rise and compare the sum to a distribution of containment failure pressure to obtain a branch point probability. The containment failure pressure (a "reference parameter") is specified through input for that node.

From the discussion above, it becomes apparent that there are at least three different types of questions for the event tree. They are those for which the user supplies only branch point probabilities, those for which the user supplies "parameter" values as well as branch point probabilities, and those for which the user supplies a list of "parameters" to be added and "reference parameters" to which the sum is to be compared. In fact, there are six different types of questions distinguished by the program. The remaining three types arise by considering the three types mentioned above as being either independent of or dependent on prior events in the tree. A summary of the different question types is shown below in Table A.1.

Table A.1

SUMMARY OF THE DIFFERENT QUESTION TYPES
FOR THE EVENT TREE PROGRAM

	Dependency upon prior events	
	Independent	Dependent
User Supplies Branch Point Probabilities Only	Type 1	Type 2
User Supplies Branch Point Probabilities and Parameter Values	Type 3	Type 4
User Specifies a List of Parameters to be Summed and Compared to Reference Parameters to Obtain Branch Point Probabilities	Type 5	Type 6

For those questions which are dependent upon prior events, different "dependency cases" are defined for which different sets of branch point probabilities are supplied. The "dependency cases" are described by specifying branches which must have been or must not have been taken for a series of key questions. To specify a branch that must have been taken the question number and the branch number are supplied to the program in the set of data for that "dependency case". To specify that a branch must not have been taken, the negative of the branch number is supplied to indicate a "not" condition. Using this strategy, many different "dependency cases" can be specified.

Marching through the event tree and finding the probability of each of the pathways would be useless without some means of condensing all of the different outcomes into some more tangible form. Thus the program was written to bin all of the different outcomes, in some user specified fashion, for the output. This binning is performed based upon certain key characteristics by which the user would like to be able to differentiate the output. For example, for the SARRP analysis we were interested in the fraction of the sequence initiating frequency which would result in different modes of early and late containment failure, with containment sprays operating or not, with different levels of secondary containment bypass, etc.

Based on these needs the program was set up to have characteristically different "dimensions" for binning. These "dimensions" are items such as those mentioned in the previous paragraph. Within each of these "dimensions", different bins are specified. For example, in the early containment failure category there may be several different levels of containment leakage as well as gross failures due to several different causes. In the case of containment sprays, commonly considered bins were different combinations of early and late spray failure and success. The binning information for the SARRP analyses was chosen to adequately describe scenarios such that fission product source terms could be assigned to the scenarios without requiring an overly conservative binning of the outcomes.

The binning is completely user specified. Input is prepared to specify the number and title of each of the different "dimensions" and the number and title of each of the bins within each of the dimensions. Then information is provided identifying combinations of key questions and branches which must or must not have been taken for an outcome to fall within each of the respective bins in each "dimension". The output then consists of aggregate probabilities of occurrence of different combinations of the various "dimensional bins".

With this background description, we will now proceed to describe the format of the input. A few key points are worth mentioning. While titles are supplied for each of the questions and branches and the questions are numbered in the input, the program does not use them. The program knows the questions and branches by number only (both assigned in order of occurrence). The titles of the questions and the branches are provided in the input for the ease of the user in preparation of the input deck.

Table A.2 provides a sample input deck constructed solely for the purpose of familiarizing the novice with the construct of the input. It deals with early failure of containment in a sub-atmospheric PWR containment due to an early hydrogen burn. The discussion of the input follows in Table A.3 with reference to line numbers in the sample input found in Table A.2.

Table A.2
Sample Problem Input

<u>Line No.</u>

<u>Input</u>

```
 1 SAMPLE - Early failure due to H2 burning in S3D at a PWR
 2       3     1.0     1.0     1.0       8 1.0E-04 1.0E-07
 3    Nwal   Pinit   Pinit   Pinit  Nquest  Prntol   Toler
 4   1 Is there pre-existing leakage or isolation failure?
 5       4     EE3     EE2     EE1     EE0
 6       1       1       2       3       4
 7           0.000   0.000   0.013   0.987
 8           0.000   0.002   0.028   0.970
 9           0.000   0.002   0.051   0.947
10   2 Initial break size
11       4       A      S1      S2      S3
12       1       1       2       3       4
13           0.000   0.000   0.000   1.000
14           0.000   0.000   0.000   1.000
15           0.000   0.000   0.000   1.000
16   3 Induced failure in primary system?
17       5       A      S1      S2      S3    none
18       2       1       2       3       4       5
19       2
20       1       2
21               4
22              S3
23           0.000   0.000   1.000   0.000   0.000
24           0.250   0.000   0.250   0.000   0.500
25           0.000   0.000   0.000   0.000   1.000
26         Otherwise
27           0.000   0.000   0.000   0.000   1.000
28           0.000   0.000   0.000   0.000   1.000
29           0.000   0.000   0.000   0.000   1.000
30   4 Sprays on early?
31       2     ESp   noESp
32       2       1       2
33       5
34       1       1
35               1
36             EE3
37           0.000   1.000
38           0.000   1.000
39           0.000   1.000
40       2       1       2
41               2       1
42             EE2       A
43           1.000   0.000
44           1.000   0.000
45           1.000   0.000
46       2       1       2
47               2       2
```

Table A.2 (cont.)
Sample Problem Input

```
Line No.
                            Input

48             EE2      S1
49           0.900   0.100
50           0 900   0.100
51           0.900   0.100
52       3       1       2       2
53               2      -1      -2
54             EE2     noA    noS1
55           0.000   1.000
56           0.000   1.000
57           0.000   1.000
58         Otherwise
59           1.000   0.000
60           1.000   0.000
61           1.000   0.000
62   5 Early baseline pressure
63       1   Pbase
64       4       1
65       5
66       3       1       1       4
67              -1      -2       1
68           noEE3   noEE2     ESp
69           1.000
70           1.000
71           1.000
72       1
73       1  20.000
74          20.000
75          20.000  EPbase
76       3       1       1       4
77              -1      -2       2
78           noEE3   noEE2   noESp
79           1.000
80           1.000
81           1.000
82       1
83       1  40.000
84          40.000
85          40.000  EPbase
86       2       1       4
87               2       1
88             EE2     ESp
89           1.000
90           1.000
91           1.000
92       1
93       1    15.0
94            15.0
```

Table A.2 (cont.)
Sample Problem Input

```
Line No.
                          Input

  95                15.0  EPbase
  96       2           1       4
  97                   2       2
  98                 EE2   noESp
  99               1.000
 100               1.000
 101               1.000
 102       1
 103       1        20.0
 104                20.0
 105                20.0  EPbase
 106          Otherwise
 107               1.000
 108               1.000
 109               1.000
 110       1
 111       1        14.7
 112                14.7
 113                14.7  EPbase
 114    6 Maximum break size in primary system
 115       4           A      S1      S2      S3
 116       2           1       2       3       4
 117       7
 118       2           2       3
 119                   4       5
 120                  S3    none
 121               0.000   0.000   0.000   1.000
 122               0.000   0.000   0.000   1.000
 123               0.000   0.000   0.000   1.000
 124       2           2       3
 125                   3       5
 126                  S2    none
 127               0.000   0.000   1.000   0.000
 128               0.000   0.000   1.000   0.000
 129               0.000   0.000   1.000   0.000
 130       2           2       3
 131                   2       5
 132                  S1    none
 133               0.000   1.000   0.000   0.000
 134               0.000   1.000   0.000   0.000
 135               0.000   1.000   0.000   0.000
 136       1           3
 137                   4
 138                  S3
 139               0.000   0.000   0.000   1.000
```

Table A.2 (cont.)
Sample Problem Input

```
Line No.
                       Input

140           0.000   0.000   0.000   1.000
141           0.000   0.000   0.000   1.000
142       1       3
143               3
144              S2
145           0.000   0.000   1.000   0.000
146           0.000   0.000   1.000   0.000
147           0.000   0.000   1.000   0.000
148       1       3
149               2
150              S1
151           0.000   1.000   0.000   0.000
152           0.000   1.000   0.000   0.000
153           0.000   1.000   0.000   0.000
154         Otherwise
155           1.000   0.000   0.000   0.000
156           1.000   0.000   0.000   0.000
157           1.000   0.000   0.000   0.000
158   7 Hydrogen burn before vessel breach?
159       2     EHB   noEHB
160       4       1       2
161       6
162       4       1       1       4       6
163              -1      -2       1       1
164           noEE3   noEE2     ESp       A
165           0.000   1.000
166           0.100   0.900
167           0.100   0.900
168       1
169       2     0.0     0.0
170            25.0     0.0
171            50.0     0.0   DP-EH
172       4       1       1       4       6
173              -1      -2       1       2
174           noEE3   noEE2     ESp      S1
175           0.000   1.000
176           0.000   1.000
177           0.100   0.900
178       1
179       2     0.0     0.0
180             0.0     0.0
181            35.0     0.0   DP-EH
182       5       1       1       4       6       6
183              -1      -2       1      -1      -2
184           noEE3   noEE2     ESp     noA    noS1
```

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Table A.2 (cont.)
Sample Problem Input

```
Line No.
                                  Input

185            0.000   1.000
186            0.000   1.000
187            0.000   1.000
188        1
189        2     0.0     0.0
190              0.0     0.0
191              0.0     0.0   DP-EH
192        3       1       4       6
193                2       1       1
194              EE2     ESp       A
195            0.000   1.000
196            0.000   1.000
197            0.100   0.900
198        1
199        2     0.0     0.0
200              0.0     0.0
201             35.0     0.0   DP-EH
202        3       1       4       6
203                2       1       2
204              EE2     ESp      S1
205            0.000   1.000
206            0.000   1.000
207            0.100   0.900
208        1
209        2     0.0     0.0
210              0.0     0.0
211             25.0     0.0   DP-EH
212           Otherwise
213            0.000   1.000
214            0.000   1.000
215            0.000   1.000
216        1
217        2   0.000   0.000
218            0.000   0.000
219            0.000   0.000   DP-EH
220     8 Does containment fail due to an early hydrogen burn?
221        2      EH    noEH
222        5       1       2
223        2       1       2
224           EPbase   DP-EH
225            'AND'
226          'NORMAL'      2     134     2.5
227                              134      15
228                               60      15
229                          CFP    MEAN   SIGMA
```

Table A.2 (cont.)
Sample Problem Input

```
Line No.
                                  Input

230  'SAMPLE Early failure due to H2 burning in S3D at a PWR
231  'OPTIMISTIC'      'CENTRAL'          'PESSIMISTIC'
232    2          'CF'  'Sprays'
233    5    5    'EE0'    'EE1'    'EE2'    'EE3'    'EH'
234    2    1       1        8
235                 4        2
236               EE0     noEH
237    2    2       1        8
238                 3        2
239               EE1     noEH
240    2    3       1        8
241                 2        2
242               EE2     noEH
243    2    4       1        8
244                 1        2
245               EE3     noEH
246    1    5                8
247                          1
248                         EH
249    2    2   'ESp'  'noESp'
250    1    1       4
251                 1
252               ESp
253    1    2       4
254                 2
255             noESp
```

Table A.3
Detailed Discussion of Sample Input

Line in Table A.2	Input Description
1	Dummy title for this set of input. Not actually used by program but made available for the user for quick identification of the input
2-3	Number of walkthroughs of the tree, the initiating frequency of each of the walkthroughs (when set equal to one, conditional probabilities are obtained), the number of questions in the tree, the print tolerance (output with aggregate probability less than the print tolerance is not found in the printed output), and the cutoff tolerance in the tree (if the probability of a pathway is reduced below the cutoff tolerance, calculations cease for that portion of the tree). The titles in line three are not used by the program but facilitate the user in preparing the input.
4	Question number one is concerned with the level of preexisting leakage or isolation failure.
5	This first node in the tree has four branches. They are titled EE3, EE2, EE1, and EE0. EE3 stands for leakage of sufficient size to be equivalent to a gross failure of containment. EE2 is leakage smaller than gross failure (in terms of amounts of fission products released) but still large enough to prevent containment failure due to long term and gradual overpressurization. EE1 is leakage too small to prevent long term overpressurization but larger than design leakage of containment. Design leakage or less is designated by EE0. These titles are not used by the program but are provided for ease of preparing and reading the input.
6	The first number is all that is actually used by the program and denotes this question as being of type 1 (see earlier discussion of question types). The other numbers are simply the branch numbers for this question which are supplied for ease of reading the input.
7-9	These three lines provide the branch point probabilities for this question for the three different walkthroughs. Each line supplies the probabilities for a different walkthrough. In this example (this will be true for all the questions in

Table A.3 (cont.)
Detailed Discussion of Sample Input

Line in Table A.2	Input Description
	this sample input), the first line represents input for an optimistic walkthrough, the third line for a pessimistic walkthrough, and the second line represents a central viewpoint.
10	Question number 2 addresses the size of the initial break in the primary system.
11-12	The question has four branches (A, S1, S2, S3) and is of type 1. The branches are "large" (A), "intermediate" (S1), "small" (S2), and "very small" (S3).
13-15	The branch point probabilities for the three different walkthroughs are given in these three lines.
16	Question 3 is concerned with the possibility of induced failures in the primary system in high pressure scenarios due to natural convection of hot gases throughout the system.
17-18	Question three has five branches (four similar to question 2 and one additional to account for no induced failure) and is of type 2. Type 2 means the branch point probabilities are dependent upon prior events such that "dependency cases" must be specified.
19	There will be two "dependency cases" specified.
20	For this first "dependency case," there is one question-branch pair specified which must either have or have not been taken previously in the tree for the following branch point probabilities to be used for this question. The question of dependency is question number 2.
21	The branch specification is 4. This means (since the branch specification is positive) that branch 4 must have been taken previously at question 2 for the following set of branch point probabilities to be used.
22	The title of the branch which must have been taken is S3. This title is not used by the program but is supplied for ease of preparation and examination of the input.

Table A.3 (cont.)
Detailed Discussion of Sample Input

Line in Table A.2	Input Description
23-25	The branch point probabilities for this dependency case for this question for the three different walkthroughs.
26	This is the second and last dependency case. In fact, it is a catchall case. That is, any paths which did not fit into any of the previous cases use this set of branch point probabilities. (Hence the "otherwise" descriptor.) This line is not actually used by the program but is another clarification feature of the input structure.
27-29	The three sets of branch point probabilities for the "otherwise" catchall case.
30-32	Question 4 addresses early spray operation, it has two branches, and is of type 2.
33	Five dependency cases are specified for this question.
34-36	The first dependency case has one question-branch pair specified, this is branch 1 of question 1 (the EL3 branch).
37-39	The branch point probabilities are for spray operation given preexisting leakage or isolation failure equivalent to gross rupture of containment.
40-42	The second dependency case has two question-branch pairs specified; these are questions 1 and 2 and branches 2 and 1, respectively, corresponding to preexisting leakage or isolation of level 2 and a large initial break in the primary system.
43-45	The branch point probabilities for spray operation for the three different walkthroughs and the second dependency case.
46-51	The third dependency case specification (leakage level 2 and intermediate initial break in the primary system) and the corresponding branch point probabilities.

Table A.3 (cont.)
Detailed Discussion of Sample Input

Line in Table A.2	Input Description
52-54	The fourth dependency case specifies a leakage level of 2 and an initial break in the primary system other than large or intermediate (signified by the negative branch number). Thus either a small or a very small initial break with a leakage level of 2 would fall into this case.
55-57	The branch point probabilities for the fourth dependency case.
58-61	The catchall branch point probabilities for question number 4.
62	Question 5 addresses the early baseline pressure in containment.
63-65	There is only one branch for this question since it is only in the tree to supply the value of the early baseline pressure "parameter". The question is of type 4, meaning it is dependent upon prior events and that a parameter value is specified. There are five dependency cases specified.
66-71	The first dependency case is specified as branch 1 of question 4 and anything but branch 1 or 2 on question 1. Since this is a single branch node, the probabilities for all three walkthroughs are all unity.
72	The value of one parameter will be specified in this case. (The value of more than one parameter can be specified at a type 3 or 4 question.)
73-75	The parameter identification number is 1 and the value of the parameter for the three different walkthroughs is 20.0.
76-113	Specification of the remaining four dependency cases, and the associated branch point probabilities, parameter identification numbers and parameter values.
114	Question number 6 combines the information from questions 2 and 3 to simplify the specification of dependency cases in later questions. No new information is gained by this node, but past information is summed up into a more convenient form.

Table A.3 (cont.)
Detailed Discussion of Sample Input

Line in Table A.2	Input Description
115-117	Question 6 has four branches and is of type 2. There are seven dependency cases specified.
118-157	Specification of the seven different dependency cases and the branch point probabilities. Note that since this question serves in a summary manner, the branch point probabilities are all unity or zero and are invariant with the three different walkthroughs.
158	Question 7 addresses the probability of a hydrogen burn before vessel breach and the magnitude of such a hydrogen burn.
159-161	Question 7 consists of two branches and is of type 4. Six dependency cases are specified.
162-167	The first dependency case has four question-branch pairs specified. They are "not" branch 1 or 2 of question 1 and branch 1 of both question 4 and 6. The three sets of branch point probabilities are also supplied.
168	The value of one parameter will be specified for this dependency case.
169-171	The parameter identification number is 2. (This parameter is the pressure rise associated with the hydrogen burn.) The values of the parameter are 0., 25., and 50., for the three different walkthroughs if branch 1 is taken. Otherwise the values are all zero, since the other branch involves no combustion. (The value of the parameter for a given branch appears under that branch in order of the different walkthroughs.)
172-219	Specification of the remaining five dependency cases along with the parameter identification and values.
220	Question 8 addresses the probability of containment failure due to an early hydrogen burn.
221-222	Question 8 has two branches (a necessity for this type of question) and is of type 5. This means it is of the type which compares a sum of specified parameters to some reference parameters and the branch point probability will be internally calculated by the program.

Table A.3 (cont.)
Detailed Discussion of Sample Input

Line in Table A.2	Input Description
223-224	There are two parameters specified to manipulate. These are parameters 1 and 2. These are the values of early baseline pressure and early hydrogen burn pressure rise respectively. The titles in line 224 are provided entirely for clarification and are not actually used in the program.
225	The parameters are to be "added" together. That is they are to be summed. Other options here are 'MAX' and 'MIN' which instruct the program to take the maximum or minimum of the specified parameter values respectively.
226-229	The outcome of the above mentioned manipulation of parameter values is to be compared to a normally distributed reference parameter, hence the 'NORMAL' descriptor in the input. (In this case the reference parameter is the containment failure pressure.) There are two reference parameters, each of which has a value specified for the three different walkthroughs. For this case, these are the mean and the standard deviation of the normal distribution. Another possibility for this type of question is a threshold comparison in which case 'THRESH' would appear instead of 'NORMAL' and only one reference parameter would need to be specified, namely the value of the threshold. The titles supplied in line 229 are for clarification purposes and are not used by the program.
230	Problem title. (Will be printed in the output.)
231	Titles for the three different walkthroughs. (Will be printed in the output.)
232	The number of binning "dimensions" is specified to be 2. The titles of these "dimensions" are CF and Sprays.
233	The first dimension consists of five bins. Five "pathways" for binning into these five bins are specified in the input. (The number of pathways must always equal or exceed the number of bins unless a vacuous bin has been defined.) The bin titles for this dimension are EE0, EE1, EE2, EE3, and EH.

Table A.3 (cont.)
Detailed Discussion of Sample Input

Line in Table A.2	Input Description
234-236	These lines describe the first "pathway". There are two question-branch pairs specified for this pathway and any outcomes of the tree matching this "pathway" criterion are to be place in bin number 1. The question branch pairs are branch 4 of question 1 and branch 2 of question 8.
237-248	Specification of the remaining four pathways. The first three utilize two question-branch pairs and the last only one pair.
249	Dimension 2 consists of two bins and has two "pathways" specified. The titles are ESp and noESp.
250-252	There is one question-branch pair specified for the first "pathway". Any outcomes of the tree which match this outcome will be placed in bin number 1 of this dimension.
253-255	The second and last "pathway" specification. Outcomes matching this criterion will be placed in bin number 2 of this dimension.

Appendix B

CONTAINMENT EVENT TREE FOR SURRY

We evaluated the response of the Surry containment to core-melt accidents within the framework of an event tree constructed for PWRs using large, dry containments. Because the event tree has 59 top events, many of which have more than two branches, it is impractical to present the tree in graphic form. The top events are listed in Table B-1.

The coordination of the containment analysis with the assessment of core-melt sequences was accomplished largely through the definition of a set of plant-damage states. These plant-damage states help to assure that the core-melt sequences are defined in sufficient detail to reflect the different conditions that could have important, unique effects upon containment response. They also serve to group sequences that would be similar in terms of their effects on containment, but that are evaluated separately for convenience in the core-melt analysis, in order to provide an appropriately limited number of entry conditions for the containment-response analysis. The plant-damage states for Surry reflect consideration of several parameters that could have an impact on the progression of a core-melt accident:

- The size and location of the breach in the reactor coolant system,
- Whether or not there is water in the reactor cavity at the time of the breach of the reactor vessel following core melt,
- The status of the containment spray and heat removal systems,
- Whether the sequence involved failure of the containment prior to melting of the core, and
- Whether or not the accident involved a bypass of containment.

From this list, a set of four parameter categories was developed. The possible states for each of these categories were assigned a letter, leading to the definition of four-character designators for each plant-damage state. The parameter categories and their states are as follows:

1. The integrity of the RCS pressure boundary:

    a LOCA leading to low pressure in the RCS prior to breaching of the reactor pressure vessel,

S_2	Small LOCA leading to intermediate pressure in the RCS prior to breaching of the reactor pressure vessel,
S_3	Very small LOCA, with high pressure in the RCS prior to breaching of the reactor pressure vessel,
T	RCS is essentially intact and at high pressure prior to the vessel breach (the pressurizer relief valves may be cycling), and
V	LOCA that bypasses the containment boundary.

2. Whether or not water from the RWST has been discharged into containment:

Y	The RWST inventory has been discharged to containment, either by the emergency injection systems or by the containment spray injection system, and
N	The RWST inventory has not been discharged to the containment.

3. Whether or not containment heat removal is available:

Y	Containment heat removal is available, and
N	Containment heat removal is not available.

4. The status of the containment spray systems:

B	Both the containment spray injection and the containment spray recirculation systems are available.
I	The containment spray injection system is available, but the recirculation system has failed,
R	Containment spray recirculation is available, but the injection system failed (possible in Surry because of the separate spray injection and recirculation systems), and
N	Neither injection nor recirculation flow is available.

The plant-damage states for the Surry analysis are defined in Table B-2.

The following sections describe the events in the containment event tree, their relationships to the other events in the event tree, and the rationale for the quantification of their branch-point probabilities for each of the Surry plant-damage states and for each of the three evaluations, or walkthroughs, of the event trees (optimistic, central, and pessimistic). Table 2.3 of the main report provides a synopsis of the walkthroughs for plant-damage state S_2YYB. The detailed computer input for each of the event tree questions is provided in Appendix C for reference purposes.

Question 1. Is ac power available after the initiating event?

The availability of electric power was reflected in the containment event tree to permit direct treatment of station-blackout sequences, such as sequence TMLB' from the Reactor Safety Study (RSS, Ref. 1), including their effects on the availability of containment sprays. The event acts as a switch; the branches have probabilities of 0.0 and 1.0 for the affirmative and negative, respectively, for station-blackout sequences, and the reverse for all others. The use of plant-damage states, which explicitly identify the status of the containment spray systems, eliminated the need for this event for the present analysis.

Question 2. Does core water makeup fail before containment overpressurization?

The failure of containment prior to melting of the core can have a significant influence on the magnitude of the resulting source term. This branch point was originally included in the event tree to treat the sequence involving failure of the containment spray injection system, such that there would be insufficient water in the containment sump to effect recirculation cooling of the core--sequence S_2C from the RSS (Ref. 1). This sequence has been discounted, since the success of emergency coolant injection is expected to provide sufficient inventory in the sump to permit the initiation of recirculation.

The status of this question is determined directly by the plant-damage states. Specifically, for sequences assigned to damage state AYNB (sequences AF_1F_2 and $S_1F_1F_2$), the containment is expected to experience overpressurization prior to core melt due to the unavailability of service water cooling for the containment heat exchangers. Thus, for damage state AYNB, the negative branch for question 2 is always followed. For all other plant damage states, core melt precedes containment failure, and the positive branch is always followed.

Question 3. What is the level of pre-existing containment leakage or isolation failure?

The magnitude of any leakage path can have important effects on the progression of an accident and its source term. A large leak can preclude overpressurization of containment and may direct the release through a different path from that which might otherwise have been expected.

We considered four levels of containment leakage to be of interest based on accident phenomenology. The size ranges for these levels were determined based on the results of MARCH calculations performed by Battelle (BMI, Ref. 2). The four levels are summarized as follows:

Description	Size Range
(1) Leakage within limits imposed by the technical specifications	<0.004 in^2
(2) Leakage greater than that allowed by technical specifications, but insufficient to preclude gradual, long-term overpressurization	0.004 to 4.0 in^2
(3) Leakage sufficient to prevent gradual overpressurization, but insufficient to depressurize containment within about two hours	4 in^2 to 1 ft^2
(4) Leakage sufficient to depressurize the containment in two hours or less	>1 ft^2

Weinstein (NRR, Ref. 3) reported the frequency of observed leaks at nuclear power plants based on licensee event reports. We analyzed Weinstein's data assuming a binomial distribution for leak occurrence. The analysis yielded 5th, 50th, and 95th percentile probabilities for level (2) leaks of .017, .033, and .058, respectively, and 4×10^{-5}, 5×10^{-4}, and 2×10^{-3}, respectively, for level (3) leaks. Most of Weinstein's PWR data are for containments operated at atmospheric pressure. Pre-existing leaks at subatmospheric containments would be limited by the capacity of the vacuum pumps to about .07 sq. in. Therefore, for Surry, we excluded observations of leaks in the larger size range. We determined the 5th, 50th, and 95th percentile probabilities for level (2) leaks at Surry to be .013, .028, and .051, respectively. Pre-existing level (3) leaks at Surry would be impossible.

The RSS (Ref. 1) estimated a probability of isolation failure of .002. Major contributors were inadvertent opening of a containment purge valve with coincident failure of a radiation interlock, failure of containment spray injection isolation, and failure of low pressure recirculation isolation. RSSMAP (Ref. 4) increased the probability to .007 to reflect concerns about a recently discovered large leak at another plant. On the other hand, IDCOR (Ref. 5) estimated isolation failure--based on coincident opening of double purge valves--to be no greater than 10^{-6}. We have taken the probability of isolation failure at both plants to be negligible (optimistic), or the RSS value (central and pessimistic). We added the probability of isolation failure to the probability of pre-existing leakage, assuming that the two were independent.

We recognized that the probability of isolation failure could be a function of ac power availability; however, we did not have sufficient information to quantify the dependence. We also recognized that external events such as earthquakes could increase the probability of leakage or isolation failure, but we did not attempt to quantify that probability.

We recently received a draft report by Pacific Northwest Laboratories (PNL, Ref. 6) entitled "Reliability Analysis of Containment Isolation Systems." This report provides a detailed evaluation of applicable licensee event reports and integrated leak test reports. PNL's results do not distinguish between pre-existing leaks and failures of containment isolation, but overall they appear to be consistent with the values we have calculated.

The outcomes and probabilities for this question are therefore summarized as follows:

Level of Isolation Failure	Branch Point Probabilities		
	Optimistic	Central	Pessimistic
1. <0.004 in^2	--	--	--
2. 0.004 to 4.0 in^2	1.3×10^{-2}	2.8×10^{-2}	5.1×10^{-2}
3. 4 in^2 to 1 ft^2	1.3×10^{-2}	2.0×10^{-3}	2.0×10^{-3}
4. >1 ft^2	ε	ε	ε

Question 4. Where is the initial reactor coolant system break?

The location of the initial RCS break determines in part the pathway taken by fission products escaping from the RCS, and consequently the magnitude of the source term. The break location was assessed to be related, at least in part, to the size of the initial break; the outcomes for this question reflect four break sizes of interest:

- Large LOCA (equivalent to event A),
- Medium LOCA (event S_1),
- Small LOCA (event S_2), and
- Very small LOCA (event S_3 and cycling pressurizer relief valves)

Examination of P&IDs showed an approximately equal number of connections in the range of 1 to 2 inches on hot legs and cold legs. However, because of the greater number of instrumentation connections on the cold legs, we estimated that a break in the S_2 size range would be more likely to be on a cold leg. Nearly all connections in the S_1 size range (2 to 6 inches) are on cold legs, and 40% of connections larger than S_1 but smaller than main reactor coolant piping are on the cold legs. We assumed the probability of breaks in the S_1 and intermediate size ranges would be proportional to the number of connections on the hot and cold legs. We assumed that breaks of main reactor coolant piping could occur on hot or cold legs with equal frequency. S_3 LOCAs (.5 to 1 inch equivalent) were assumed to be pump seal failures and hence would always be on the cold legs.

Question 5. What is the size of the initial reactor coolant system break?

The size of the initial RCS break determines the pressure in the RCS at the time of core melt and the relative timing of the discharge of the cold-leg accumulators, which in turn affect both the behavior of the core debris during and following ejection from the reactor vessel, as well as the discharge of fission products to the containment atmosphere. The size of the initial break is part of the definition of the plant-damage states, and the choice of branch point for this question is therefore dictated by each state entering the event tree.

Question 6. Is the containment initially bypassed?

Like question 5, the question of whether the containment is initially bypassed is determined directly by the core-melt sequences. An interfacing systems LOCA, assigned to plant-damage state V, would bypass the containment, so that blowdown from the reactor coolant system would not enter containment. All other sequences do not result directly in containment bypass.

Question 7. Are the steam generators wet or dry?

Steam generators would always be wet for sequences in which auxiliary feedwater functioned. In sequence T_1LDCF_1, for example, no feedwater is available. Both BMI (Ref. 2) and IDCOR (Ref. 5) show steam generator dryout well in advance of reactor vessel breach for a station blackout sequence with failure of the turbine-driven auxiliary feedwater pump. We evaluated the likelihood of the steam generators being wet by examining the specific sequences for the plant damage states. For damage state TNNN, the steam generators would be dry; for all others, we would expect auxiliary feedwater to be functioning. Whether the steam generator tubes are covered during meltdown could be an important determinant of the radioactive release.

Question 8. Do the fan coolers fail to operate before core degradation?

Surry does not have a fan-cooling system for emergency operation. Containment heat removal is accomplished through the containment spray system.

Question 9. Do the sprays fail to actuate in the injection mode before core degradation?

The operation of the containment spray system early in the accident has several important effects on subsequent phenomena: (1) it limits the containment pressure attributed to the generation of steam; (2) it provides water directly to the reactor cavity, which influences the behavior of core debris following vessel failure; and (3) it tends to deinert the containment atmosphere, providing for the possibility of a hydrogen burn. The availability of the spray system is defined directly by the plant-damage state entering the containment event tree. Whether or not the spray system is demanded to actuate early in the accident is a function principally of the rate of discharge from the primary system to the containment and the rate of leakage from the containment. At a subatmospheric plant like Surry, where the fan coolers are non-emergency and trip on safety actuation, the containment spray setpoint of 10.3 psig would be reached in about 1-2 hours (BMI, Ref. 2) for S_2 or S_3 LOCAs. However, in the event of a large containment leak or isolation failure, the setpoint would not be reached prior to vessel breach for small LOCAs. For large and intermediate LOCAs, the setpoint would be reached almost immediately, even with isolation failures. The spray setpoint would not be reached prior to vessel breach in the event of a large containment bypass.

For Surry, given availability of the system as defined in the plant-damage state, we assumed that spray operation was "certain" for all large breaks, for intermediate breaks without containment bypass, and for all smaller breaks without bypass or level (2) leakage or isolation failure. For all other sequences at Surry, we assumed initial spray operation to be "impossible."

Question 10. Do the containment sprays fail to actuate in the recirculation mode before core degradation?

If sprays operated in the injection mode, they would only fail in the recirculation mode if the plant-damage state involved a recirculation failure.

Question 11. To what degree, if any, is the auxiliary building initially bypassed?

Some reduction in the fission-product source term will occur if the release path is through the auxiliary building.

The RSS (Ref. 1) allowed no credit for deposition of fission products in the auxiliary building. BMI (Ref. 2) allowed full use of the auxiliary building for holdup of fission products released through an isolation failure.

In this analysis, we considered the possibility that the auxiliary building would be only partially effective, either because the release occurred in the upper, more open part of the building, or because blowdown from containment damaged the auxiliary building to the extent that an essentially direct path to the atmosphere was available.

We considered preexisting leaks or isolation failures in the larger range (level 2) "likely" to pass through the auxiliary building, because most containment penetrations lead into the auxiliary building, and "unlikely" to result in partial bypass. The complete opening of a purge line would cause a total bypass of the auxiliary building, but such an event was assessed by IDCOR (Ref. 5) to be extremely unlikely. The only event considered to result in a total bypass was a steam generator tube rupture with a dry steam generator; such an event was considered "certain" to bypass the auxiliary building.

Question 12. Where, if at all, is there a temperature induced failure of the reactor coolant system during core degradation?

Temperature-induced failures of the reactor coolant system have not been considered in most risk assessments (Refs. 1, 4, 7-10). However, recent analyses (NPR, Ref. 11) show gas temperatures as high as 2000 F for the station-blackout sequence, and similarly high temperatures could be expected for very small LOCAs with failure of emergency coolant injection. RCS pressure is expected to be at the pilot-operated relief valve setting for accidents initiated by transient events and at system pressure for LOCAs in the S_3 size range (BMI, Ref. 2; IDCOR, Ref. 5; SASA, Ref. 12). Based on these observations, CLWG and others have raised the possibility of induced failure in some part of the RCS. IDCOR (Ref. 5) assumed that the induced LOCA would be a failure of the reactor coolant pump seals, which would convert an S_3 LOCA into an S_2 LOCA. A seal LOCA is considered especially likely for station blackouts, because of the failure of seal coolant. Full rupture of a hot leg is also considered possible. We also considered the possibility of a steam generator tube rupture (SGTR). The Zion-Indian Point Study (Ref. 13) raised the possibility of induced SGTRs, and there have been reports of steam generator tube failures even without the high temperatures and pressures expected in S_3 LOCAs or transient-initiated sequences. On the other hand, IDCOR (Ref. 5) considered SGTRs to be "not risk significant."

Induced failure is optimistic in one sense, in that later direct heating scenarios can be prevented or mitigated. On the other hand, induced hot leg failure could be pessimistic, in that there would be less retention of fission products in the RCS. On balance, we assumed the potential of induced failures to prevent early containment failures would be more weighty than the potential to increase release of fission products from the RCS.

Four outcomes for this event were therefore considered: (1) no induced failure, (2) hot-leg failure, (3) cold-leg failure, and (4) SGTR. We have taken induced failure to be "certain" (optimistic), "indeterminate" (central), or "unlikely" (pessimistic) for sequences in which RCS pressure is maintained at the relief valve setting or system pressure. We have taken induced failure to be "impossible" for S_2 and larger LOCAs. We estimated the probability of an induced SGTR to be "impossible" (optimistic), "remotely possible" (central), or "unlikely" (pessimistic), based on the available analyses. The probability splits are summarized as follows (for sequences with cycling relief values or very small LOCA leakage rates):

	Probability		
	Optimistic	Central	Pessimistic
Hot-leg failure	0.1	0.25	--
Cold-leg failure	0.9	0.25	0.1
SGTR	--	0.001	0.1
None	--	0.499	0.8

Question 13. What is the size of the induced reactor coolant system failure?

We assumed rupture of a hot leg to be a large break; temperature-induced seal LOCAs and SGTRs were assumed equivalent to an S_2 LOCA.

Question 14. What is the primary system pressure during core degradation? What would be the containment pressure increment from a primary system blowdown?

BMI (Ref. 2), IDCOR (Ref. 5), and SASA (Ref. 12) all indicated primary system pressures remaining at relief-valve settings for sequence T_1LDCF_1 (station blackout), a few hundred psi for sequence S_2D_1, and a few tens of psi for large breaks. We considered three pressure regimes: "high" pressure, in which the accumulators would not discharge at all prior to vessel breach, "intermediate" pressure sequences, in which the accumulators discharge at least partially, but the RCS pressure remains significantly above containment pressure until vessel breach, and "low" pressure sequences, in which the accumulators fully discharge and the RCS pressure drops to nearly containment pressure.

BMI (Ref. 2), IDCOR (Ref. 5), SASA (Ref. 12), and CLWG (Ref. 13) all indicate containment pressure increments of 8-15 psi at the time of vessel breach for high pressure sequences. Smaller pressure rises are seen for S_2 LOCAs and essentially none for large breaks. We have taken the increment of containment pressure due to primary depressurization to be 15 psi for high pressure sequences, 7 psi for intermediate pressure sequences, and zero for low pressure sequences.

Question 15. At what level, if any, is containment bypassed during core degradation?

If the initiator is a large SGTR or interfacing LOCA, or if a large temperature-induced SGTR were to occur, an essentially complete bypass of containment would result. Smaller breaches were assumed to be partial bypasses. For complete bypasses, the RCS is depressurized without pressurizing containment.

Question 16. What is the rate of blowdown to containment during core degradation?

If there is no containment bypass (questions 6 and 15), the blowdown rate is determined directly by break size. If the containment is bypassed, the blowdown rate to containment is considered to be essentially zero.

Question 17. Do the sprays fail to actuate following the induced LOCA, if any?

If the sprays were operating before the induced LOCA, they continue to operate. If the sprays were operable but had not been actuated, the same probabilities as in question 9 are used with the new break size to determine whether they will be actuated.

Question 18. Is there containment heat removal during core degradation?

The status of this question is also indicated by the plant damage states, which specify whether containment heat removal is available. As a practical matter, if the containment spray system is operating and the positive branch is followed at question 2 (indicating that loss of containment cooling has not led to overpressurization of the containment prior to core melt), then containment heat removal will be available.

Question 19. At what level, if any, does the containment fail due to steam pressurization before vessel breach?

We considered two levels of containment failure following overpressurization (i) leakage sufficient to preclude gradual overpressurization, but insufficient to depressurize containment within about two hours, and (ii) gross failure resulting in depressurization in less than two hours.

The CPWG (Ref. 15) provided "upper bound" estimates of leak area versus pressure for several plants, and of leak area versus time at temperature for Peach Bottom. For Surry, the primary source of leakage was the personnel air lock. The pressure-dependent leak areas are listed in Table 2.5 of the main report.

The CPWG did not provide "lower bound" or "central" estimates, although there is an implication that the leak areas for these cases would be negligible. Even the upper bound leak areas for Surry and Zion are very small compared to those which would be required to preclude structural failure from gradual overpressurization. The leak area which would preclude overpressure failure is about 20-26 sq. in. if one does not consider internal heat sinks and condensation on containment walls. With consideration of heat sinks and condensation, MARCH runs have sometimes shown failure precluded with leaks as small as 4-6 sq. in. (SASA, Ref. 12; BNL, Ref. 16). If a minimum of 4 sq. in. is considered necessary to preclude overpressure failure, the CPWG upper bound leak model would not preclude structural failure unless containment survived well past its mean failure pressure. Hence, the CPWG leakage model leads to the conclusion that the development of a pressure relieving leak is at best "remotely possible".

A recent Sandia test on a 1/8-linear-scale steel containment model produced results which would, at first glance, appear to corroborate the CPWG model; that is to say, significant leakage did not occur prior to structural failure. However, it is very risky to extrapolate these results to the present containment or, for that matter, to any of the reference plants. First, the Surry containment is steel lined, reinforced concrete, not a steel structure. (Even the reference plants that have steel containments also have a concrete shield, whereas the experiment did not.) Second, the deformation patterns in the experiment indicate that leakage around a penetration seal may have been imminent.

Finally, IDCOR (Ref. 5) presented a case that for Zion, pressure-induced lekage would be a more likely failure mode than gross structural failure.

In terms of source terms and consequences, it is more optimistic for containment to fail via a pressure-relieving leak than a gross rupture. Hence, we adopted IDCOR's position that "leak-before-break" is the "likely" outcome for the optimistic walkthrough.

For the "central" and "pessimistic" walkthroughs, we utilized the conclusion, based on the CPWG model, that leak-before-break was at best "remotely possible."

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If failure has been caused by hydrogen burning, we expect that the loading time would be too short for a pressure-relieving leak to develop, and failure, if any, is a gross rupture.

Question 20. What is the containment pressure before vessel breach?

MARCH and MAAP calculations by IDCOR, BMI and SASA generally agree on the baseline pressure before vessel breach within about 10 psi. It is true that the containment pressure is not constant. However, the most important point at which the pressure has to be known is just prior to vessel breach. The containment pressures at Surry have been taken to be as follows:

	With Containment Heat Removal	Without Containment Heat Removal
No leakage	5 psig	25 psig
Large containment leak	0 psig	5 psig

Question 21. Is there a hydrogen burn before vessel breach? If so, what is the pressure increment from such a burn?

The likelihood of a hydrogen burn before vessel breach depends on whether a combustible mixture develops and whether an ignition source is present. The hydrogen in containment will not be combustible if the containment is steam inerted or the hydrogen concentration is below the lean combustion limit. If the sprays operate, steam inerting is precluded. For the atmosphere to be combustible, however, an amount of hydrogen equivalent to about 40% zircaloy oxidation must have been generated and released to containment.

The RSS (Ref. 1) estimated that hydrogen produced before vessel breach would be equivalent to 75% ± 25% zircaloy oxidation. CLWG (Ref. 14) and SASA (Ref. 17) calculations for Sequoyah ranged in in-vessel hydrogen production from 35% to 100% zircaloy oxidation. IDCOR calculated about 25% in-vessel zircaloy oxidation for Sequoyah. A separate CLWG submittal (Ref. 18) used a lower bound of 25% and an upper bound of 100% for atmospheric and subatmospheric PWR containments. BMI-2104 calculations for Surry S_2D_1 showed about 50% oxidation occurring during core heatup and another 10% to 40% occurring during core slumping, amounting to a total of 60% to 90%. The SARRP Phenomena Assessment Task Force (PATF, Ref. 19) set the total lower and upper bounds at 10% and 100%, respectively, for a station blackout accident at Surry. Sandia (HYDR, Ref. 20) estimated that steel oxidation could add another 50%. All estimates depend to some extent on the accident sequence; however, the variation among sequences is small compared to the variation between estimates.

Given this variety of possible choices, we selected 25% zircaloy oxidation as the optimistic estimate, 50% as the central estimate, and 100% as the pessimistic estimate. The fraction of core oxidized in the TMI-2 accident (about one-half) appears consistent with the central estimate.

The fraction of these amounts escaping from the RCS before vessel breach depends on the break size and degree of containment isolation. On the basis of MARCH calculations (BMI, Ref. 2; SASA, Ref. 12) a 75% escape fraction was estimated for large breaks, 50% for S_1, and 25% for S_2 and S_3. From these estimates, it was concluded that hydrogen burns before vessel breach could occur only for large or intermediate LOCAs without large containment leakage or isolation failure.

A burn prior to vessel breach reduces or eliminates the potential for subsequent burns that could occur with a larger fraction of hydrogen in containment, and which could consequently offer a more serious challenge to containment integrity. In the optimistic case, there is not sufficient hydrogen available to lead to burning, and therefore, although occurrence of a burn at this point would be optimistic, we took the probability of a burn for this case to be zero. For the central case, it was judged to be unlikely that there could be a hydrogen burn, due to the relatively low quantity of hydrogen available. For the pessimistic case, the quantity of hydrogen produced makes it more likely that a burn would occur; however, because it would be optimistic to assume a burn occurred, we assumed that a burn for the pessimistic case would also be "unlikely".

Containment pressure increments, if burning occurred, were calculated from CLWG (Ref. 18), which indicated a pressure rise of 70 psi due to burning of 100% Zircaloy equivalent at Surry, 35 psi due to burning of 50% Zircaloy equivalent, and 25 psi due to burning of 25% Zircaloy equivalent. The pressure increment is also dependent on the initial pressure. However, the pressure dependence is small compared to the differences between walkthroughs.

The hydrogen fractions and outcomes for this question are summarized below:

	Optimistic Estimate	Central Estimate	Pessimistic Estimate
Fraction of H_2 generated	25%	50%	100%
Escape fraction			
Large leakage rates	75%	75%	75%
Small leakage rates	50%	50%	50%
Very small leakage rates	25%	25%	25%

	Optimistic Estimate	Central Estimate	Pessimistic Estimate
Total H_2 fraction escaping RCS			
Large leakage rates	19%	38%	75%
Small leakage rates	13%	25%	50%
Very small leakage rates	6%	13%	25%
Likelihood of H_2 burn	0.0	0.1	0.1
Pressure increment--no large containment leakage			
Large leakage rates	--	25 psi	50 psi
Small leakage rates	--	--	35 psi
Very small leakage rates	--	--	--
Pressure increment--large containment leakage			
Large leakage rates	--	--	35 psi
Small leakage rates	--	--	25 psi
Very small leakage rates	--	--	--

Question 22. Does containment fail because of a hydrogen burn before vessel breach?

To evaluate this question, it is necessary to compare the peak pressure produced by the hydrogen burn to the pressure capacity for Surry. The RSS (Ref. 1) estimated the mean failure pressure for the Surry containment to be 85 psig, based on an assessment that the most likely failure mechanism was tearing of the liner. A standard deviation of 15 psi was assigned to this estimate.

More recently, Stone and Webster (S&W, Ref. 21) calculated a failure pressure of 119 psig, corresponding to general yielding of the reinforcement. Stone and Webster gave no estimate of uncertainty; however, an analogous estimate for Zion (ZPSS, Ref. 7) produced a standard deviation of about 2.5 psi.

For the pessimistic estimate, we used the RSS failure pressure of 85 psig and a standard deviation of 15 psi, and assumed a normal distribution. For the optimistic estimate, we used the Stone and Webster mean failure pressure of 119 psig with the Zion standard deviation of 2.5 psig. For the central estimate, we combined the Stone and Webster failure pressure of 119 psig with the RSS standard deviation of 15 psi. For rapid pressurization due to hydrogen burns, we assumed that the containment would fail structurally as opposed to developing leaks.

Question 23. To what degree, if any, is the auxiliary building bypassed after an early hydrogen burn?

As was the case for question 11, we considered three levels of auxiliary building bypass: no bypass (all releases from the containment pass entirely through the auxiliary building), partial bypass, and total bypass. The auxiliary building at Surry covers approximately 10% of the containment sidewall area (FSAR, Ref. 22). However, for the pessimistic walkthrough, we estimated the most likely point of containment failure to be at the juncture of the cylindrical sidewall and the upper dome, i.e., above the auxiliary building. For gross containment failure, we judged that complete bypass of the auxiliary building would be "likely" (optimistic), "almost certain" (central), or "certain" (pessimistic).

Question 24. Do the fan coolers fail after the early hydrogen burn?

There are no fan coolers for emergency operation at Surry.

Question 25. Do the containment sprays fail after the early hydrogen burn?

If the spray setpoint had not been reached previously (Question 17), an early hydrogen burn would definitely actuate them. On the other hand, a hydrogen burn could also cause the sprays to fail. To address this question, the case in which containment survives the hydrogen burn must be considered separately from the case in which containment fails.

If no containment failure occurred, it would still be possible for the pressure/temperature pulse of a hydrogen burn to cause spray failure by damaging instrumentation or burning insulation. However, it is to be noted that containment sprays survived a hydrogen burn at TMI-2 and operated normally. We estimated spray failure -- given hydrogen burn without containment failure -- to be "remotely possible."

The RSS (Ref. 1) assumed that sprays operating in the recirculation mode would inevitably fail following containment failure. The rationale was that the containment sump would become saturated as containment pressure fell and that the pumps would fail because of cavitation. More recent research has shown this assessment to be unduly pessimistic. Containment pressure is expected to decline gradually for the size of openings expected (1-2 sq. ft.), allowing the sump to become stabilized after evaporation of a small fraction of its contents. Research conducted under Task Action Plan A-43 (Ref. 23) has also shown that pumps can operate for extended periods with net positive suction head well below the design requirement. IDCOR (Ref. 5) also considered spray success to be likely.

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We estimated spray failure following containment failure to be "unlikely" for the optimistic and central cases, based on A-43 and IDCOR. For the pessimistic case, we considered spray failure to be "likely" in accordance with the more pessimistic RSS judgment.

Question 26. Is there containment heat removal after the early hydrogen burn?

The logic for this question is identical to that for question 18.

Question 27. What is the mode of reactor vessel breach?

The RSS (Ref. 1) assumed that the reactor vessel would fail either as a result of a large steam explosion or by a melt-through of the skirt, allowing the hemispherical head to detach. The ZIP study (Ref. 23) pointed out that other failure modes were equally or more likely. The ZPSS (Ref. 7) and IDCOR (Ref. 5) argued that the most probable point of failure would be a local failure at a core instrumentation tube, and that the core debris would emerge as a jet in high pressure sequences or would dribble out in low pressure sequences.

We considered four modes of reactor vessel failure in this study: a steam explosion failing the upper head, a steam explosion failing the lower head, a high-pressure ejection, and a low-pressure meltthrough.

The assessment of the likelihood of a steam explosion within the reactor vessel capable of leading directly to failure of the containment (the α mode of containment failure) is an example of a phenomenon about which there is a very wide range of opinions, indicating large uncertainties. As a consequence, we treated this issue as a sensitivity case, calculating all three walkthroughs first assuming that there is no potential for this failure mode, and then calculating the walkthroughs including the potential for a damaging steam explosion.

The probability of the α-mode was estimated in the RSS to be 0.01. More recent estimates (for example, ZPSS and IDCOR) have disputed this estimate as being unrealistic, or as being physically impossible at high pressures. SAUNA (Ref. 24) reported that triggering an explosion at high pressures might be more difficult, but that the probability of an adequate trigger being available was unknown. They cite experimental evidence that, while it may be more difficult to trigger a high pressure steam explosion, this effect is counteracted by the fact that the conversion ratio tends to be higher. The high-pressure limitation has therefore been neglected for this study.

Berman et al.. (IVSE, Ref. 25) conducted a Monte Carlo study of the probabilities of steam explosions causing failure of the reactor vessel, and for those cases in which upper head failure occurred, the subsequent probability of a large missile with sufficient velocity to fail containment. Several geometric and physical parameters used in the study were uncertain and were given uniform probability distributions which were sampled by the Monte Carlo procedure. To assess the sensitivity of the results to the assumed distributions, three different distributions were assumed for each parameter. These were labeled "low", "middle" and "high." For example, the three distributions for conversion ratio from thermal to mechanical energy were 0-1.7%, 1.7-3.3%, and 3.3-5.0%.

For our central estimate, we used the results of Berman et al., based on 'middle' distributions for all the uncertain parameters. Out of 10,000 samples, it was determined that 2126 resulted in a failure of the bottom head, while only one led to a failure of the upper head. That one also created a missile with velocity judged sufficient to threaten containment. The probability of one in 10,000 for α-mode containment failure is consistent with ZPSS and other industry-sponsored risk assessments. The majority of the members of the Steam Explosion Review Group (SERG, Ref. 26) selected "best-estimate" values of 10^{-4} within a factor of three either way. The event tree includes the potential for a steam explosion that could fail the reactor vessel upper head without failing containment. However, since the analyses by Berman, et al., showed that the slug energy required to fail the upper head would also be sufficient to produce a missile with high enough velocity to threaten containment, the probability of an upper head failure that did not fail containment was taken to be zero. The probability of a bottom-head failure due to a steam explosion was taken as 0.21. The remainder of the split fraction was assigned to the pressurized ejection mode (for higher or intermediate-pressure core melts) or to low-pressure meltthrough (for low-pressure core melts).

We selected a pessimistic value for occurrence of the failure mode of .1. This value is indicated by a number of sources. One member of the SERG selected .1 as his upper value, while another selected .04. The RSS also cited an upper value of .1 in conjunction with its best estimate of .01. A value of .1 was also used in the Gittus report (Ref. 27). Berman, et al., also obtained a value of approximately .04 if the conversion ratio is assigned its high distribution while the others are kept at their middle distributions. In addition, a recent experiment by Berman, et al., estimated the conversion ratio to be much higher than the 3.3-5.0% "high" distribution quote above. While the results of this experiment have not yet been validated, it is a further indication that this value may not be unreasonably pessimistic.

We estimated the pessimistic value for bottom-head failure due to an in-vessel steam explosion from the Monte Carlo analyses discussed above. The estimate was made based on an average of the results obtained by Berman, et al., when one parameter was assigned its "high" distribution and the others were kept at their "middle" distributions. Since five parameters were varied in this fashion, the result corresponds to the average of five cases, each involving 10,000 samples. For example, a value of .59 results if the conversion ratio is assigned its "high" distribution and the others are kept at their "middle" distributions. We selected a slightly lower value, .47, which represents the average of the five cases obtained when any one parameter is assigned its "high" distribution and the others are kept at their "middle" distributions. The remainder of the split fraction was assigned as noted for the central case.

For the optimistic estimate, we used the lowest of the results obtained by Berman, et al., when one parameter was assigned its "low" distribution and the others were kept at their "middle" distributions. This resulted in no failures.

The majority of members of the SERG (Ref. 26) produced "best estimates" of the probability of α-mode containment failure of the order of 0.0001, which is the central estimate for this study. The minimum estimate ("vanishingly small") was consistent with the optimistic estimate. The mean upper limit estimate, 0.02, is low with respect to the pessimistic estimate. The results are summarized as follows:

	Optimistic Estimate	Central Estimate	Pessimistic Estimate
Upper head failure (α-mode)	0.0	0.0001	0.1
Upper head failure (no α-mode)	0.0	0.0	0.0
Bottom head failure	0.0	0.21	0.47
Pressurized ejection			
(a) High- or intermediate-pressure core melt	1.0	0.79	0.52
(b) Low-pressure core melt	0.0	0.0	0.47
Low-pressure meltthrough			
(a) High- or intermediate-pressure core melt	0.0	0.0	0.0
(b) Low-pressure core melt	1.0	0.79	0.52

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Question 28. Does direct heating of the containment atmosphere occur just after vessel breach? Also, what is the pressure increment from a steam spike alone and from a steam spike plus direct heating?

The core debris ejected from the reactor vessel after vessel breach can be quenched either by water or by direct heat transfer to the atmosphere. Both can product a pressure spike, the former by generating steam (hence the term "steam spike") and the latter by adding thermal and/or chemical energy directly to the atmosphere (hence the term "direct heating"). The two phenomena are linked because the occurrence of one subtracts from the amount of core debris energy available for the other.

Because direct heating is a basically unresolved issue which can have a large effect on our results, we considered two cases in our analyses. In the first case, we excluded direct heating and included only steam spikes. In the second case, we allowed for both to occur concurrently.

Both the CLWG (Ref. 14) and IDCOR (Ref. 5) agree that at least a fraction of the core would be involved in a steam spike if water is present to interact with the core debris after it exits the reactor vessel. For Surry, a large amount of water would be present both in the reactor cavity and on the containment floor for plant-damage states in which the containment sprays were available. For core melts that proceed at high pressure, the accumulators would discharge at the time of vessel breach, providing an additional source of water. However, for plant-damage states involving low-pressure melts without spray operation, very little water might be present in the reactor cavity, since the accumulators would have previously discharged into the reactor coolant system prior to the vessel breach. For the cases in which water was available, it was assumed that a steam spike was certain to occur. The resulting pressure in containment was estimated for the optimistic, central, and pessimistic cases.

Direct heating may occur if the reactor vessel fails at high pressure, causing a highly aerosolized jet of debris, and if the geometry of the reactor cavity area is such that there is a pathway for the aerosolized debris to disperse into the containment atmosphere. We postulated that direct heating could also occur as a result of a steam explosion that failed the upper head, providing a direct pathway to the upper containment; however, this possibility did not play a significant role in our final results.

IDCOR discounted the occurrence of direct heating by arguing that the pathways were too tortuous for the core debris to be dispersed rapidly into the containment atmosphere. CLWG,

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on the other hand, was sharply divided on the issue. One subgroup (Group A) maintained that less than 2% of the core debris could participate in direct heating, while fully 80% might participate in a steam spike. The other subgroup (Group B) had as much as 50% of the core debris participating in both thermal and chemical heating of the atmosphere, with the remainder of the core debris contributing to a steam spike.

Experiments have been conducted at SNL (HIPS, Ref 28) using 80 Kg of thermitic melt discharged under pressure into 1/10 scale cavities with and without water. Discharge into dry cavities yielded a highly aerosolized plume of ejecta, a large fraction of which was thoroughly dispersed into the atmosphere. We estimated that the high driving forces and velocities involved in high and intermediate pressure meltdowns would be adequate to disperse the ejecta not only throughout the steam generator enclosures, but throughout the reactor containment as well.

When melt was ejected into a water filled cavity, the water was immediately blown out of the cavity as a slug, which then appeared to become finely divided. Hot debris followed, and, at least prior to cavity failure, appeared to be intimately mixed with the cloud of water droplets. White clouds (apparently water fog) could be observed throughout the ejected material. We estimated for this study that an intimate mixture of hot debris and water droplets or steam would be likely to be ejected from water-filled cavities, and considered a steam spike to be assured. Direct heating was considered "impossible" for low-pressure sequences, and for steam explosions that failed the upper or bottom head. For all other sequences, direct heating was considered "certain" for sensitivity case 2 (with magnitudes adjusted for the ejection pressure), and "impossible" for sensitivity case 1.

In the pessimistic walkthrough, we took account (based on the experimenters' statement) that in a large reactor containment, as opposed to the smaller experimental setup, the debris could be blown into one part of the containment while the water could be dispersed into another part. There seemed to be some indication in the experiment that the debris was being blown through the water fog and might therefore have segregated from it given enough space. Thus in the pessimistic walkthrough, we took direct heating to be "likely", although reduced by the fraction of melt assumed water quenched, even if the cavity was water filled. It should be pointed out that, for Surry, the cavity does not fill much higher than the bottom of the reactor vessel, which differentiates it from other plants where larger amounts of water would be present (e.g., Sequoyah).

IDCOR calculated a steam spike of 15 psi (1.0 bar) for the S_2D_1 sequence, assuming that 50% of the core debris was quenched. CLWG (Ref. 14) reported that the spike from core debris quenching in water could be nil or as high as 26 psi (1.9 bar), the latter corresponding to quenching 100% of core debris. The CLWG figures were obtained without consideration of containment cooling; however, BMI-2104 calculations indicated that the effect of sprays on the steam spike would be small if one assumed, for the pessimistic case, that the debris was highly fragmented. Thus, we took the size of the steam spike to be 10 psi (optimistic), 15 psi (central), and 26 psi (pessimistic).

The data used to develop estimates of pressure increments from concurrent direct heating and steam spikes in high pressure sequences with ample cavity water are provided in Table 2.6 of the main report. The first entry is the fraction of core melt material ejected from the reactor vessel at the time of vessel breach. A 50% (IDCOR) melt ejection was taken to be optimistic, 100% (BMI) melt ejection to be pessimistic, and 75% to represent a central estimate. (CLWG did not provide estimates for the quantity of melt ejected; it was instead stipulated as part of the standard problem definition. We used the BMI-2104 calculation of the core debris mass, rather than the standard problem definition, to represent the mass involved in 100% melt ejection.) The remaining entries were obtained from CLWG. The "optimistic" values are from Subgroup A, which provided only a single estimate, whereas the "central" and "pessimistic" values correspond to subgroup B's "medium" and "high" estimates. Subgroup B's "low" estimate was not used in this analysis, since it would not have been characterized as "optimistic" by subgroup A nor as "central" by subgroup B.

The high pressure, minimal water sequences were used as bases for estimates for sequences of intermediate pressure. CLWG did not give guidance for sequences in which the ejected melt would not become fully aerosolized. We would expect a lower direct heating pulse in such sequences. However, we did not assume a corresponding increase in the size of the steam spike, because of the coarser fragmentation expected. The direct heating contribution was assumed to be one-half the difference between the direct heating plus steam spike pulse and the pulse due to steam spike alone. For low pressure sequences, no direct heating contribution was expected. For sequences that might have limited water in the cavity (for example, AB at Surry), some guidance was available from a calculation performed for CLWG with limited cavity water; the predicted steam spike for that calculation was used for the pessimistic estimate, one-half the calculated value for the central estimate, and zero for the optimistic estimate. Reasoning that the steam spike pulses expected in lower pressure water sequences would be less likely to threaten containment, it did not seem fruitful to perform extensive recalculations.

Question 29. Is there a hydrogen burn just after vessel breach? Also, what is the pressure increment from such a burn?

The total amount of hydrogen generated before vessel breach is assumed to be released to containment at the time of vessel breach, if it has not been previously released. If hydrogen has burned before vessel breach, we considered a hydrogen burn to be "impossible" at this time because of oxygen depletion and because the hydrogen concentration would be below the lean combustion limit. If there is no containment heat removal, the atmosphere would be steam inerted and a burn would likewise be "impossible".

If the atmosphere is flammable, many experts (CLWG, BMI-2104, SASA) consider a hydrogen burn to be highly probable when the core debris is first discharged from the reactor vessel. The ignition source is the hot core debris itself. Others (IDCOR) dispute this supposition on the basis that the interaction would produce such large amounts of steam as to inert the atmosphere locally. The possibility of local inerting has been addressed by making the burn probability "likely" rather than certain.

The pressure increments for the three walkthroughs are shown below. Pressure increments have been taken from a CLWG submittal (Ref. 18). The same submittal showed that the effect of sprays on the pressure increment would be small if the burn time were comparable to that which occurred in the TMI-2 accident (i.e., about 8 seconds).

Condition	Pressure Increment (psi) Optimistic	Central	Pessimistic
No large containment leakage, no prior burn	25	35	70
Large LOCA, large containment leak, no prior burn	0	25	55
Small LOCA, large containment leak, no prior burn	0	25	65
Small LOCA, prior burn	0	0	35
Otherwise	0	0	0

Question 30. Does containment fail due to a steam spike, direct heating, and/or hydrogen burn just after vessel breach?

We added the pressure increments from hydrogen burn (question 29), direct heating and/or steam spike (question 28),

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and RCS depressurization (question 14) to the baseline containment pressure (question 20) to yield a total pressure just after vessel breach. Although the pressure increments are dependent on the baseline pressure, the dependence is small when compared to the large differences between walkthroughs. This pressure was compared to the containment failure pressure, previously addressed under question 22, to evaluate the likelihood of failure. For rapid pressure spiking events, we assumed that the containment would fail structurally, rather than by a more benign leakage mode.

Question 31. What is the mode of containment failure, if any, just after vessel breach?

This question is included to summarize the outcomes of several of the preceding questions for convenience. Five possible outcomes were considered: an α-mode failure, failure due to direct heating and steam spike (with possible contributions from hydrogen burning), failure due to hydrogen burning and steam spike, failure due to steam spike plus depressurization, and no failure.

Question 32. To what degree, if any, is the auxiliary building bypassed just after vessel breach?

We assumed a complete bypass for α-mode failures; otherwise, the logic is identical to question 23.

Question 33. Do the fan coolers fail just after vessel breach?

Surry does not have an emergency fan cooling system.

Question 34. Do the containment sprays fail after vessel breach?

The logic for spray failure following containment failure is similar to that for question 25. However, in addition to the possibility of failure by a hydrogen burn damaging instrumentation or insulation or by cavitation due to containment depressurization, containment sprays could fail because of debris in the sump clogging the screens or passing through the screens and damaging the pumps. One of the sources of debris might be an energetic fuel-water interaction that swept core debris, tubing, ductwork, and insulation out of the reactor cavity. Even without a steam spike, some debris could be expected. It may be observed, for example, that the sump water at TMI-2 was laden with particulate matter.

In the absence of containment failure, we estimated containment spray failure after vessel breach to be "remotely possible" (optimistic), "unlikely" (central), or "indeterminate" (pessimistic), taking into account the results of TAP A-43 research (discussed for question 25). In the event of containment failure, spray failure was given the same likelihoods as for question 25.

Question 35. Is there an oxidation release?

In the event that the containment were to fail due to direct heating, an oxidation release would result.

Question 36. Is ac power restored after vessel breach?

Restoration of ac power for station-blackout sequences could restore containment heat removal, but could also deinert the containment atmosphere, providing an increased opportunity for a hydrogen burn. The RSS only considered restoration of ac power in sequences in a time frame that would prevent the core from melting. However, data in the RSS and in EPRI (Ref. 29) indicate a high probability that power would be restored within a few hours. After core degradation commenced, power restoration could alter the course of an accident even if vessel breach were not preventable.

EPRI data indicate conditional probabilities of power restoration to be 0.75 at 4 hours and 0.9 at 6 hours. Restoration of power within the first day is virtually assured. Restoration of power before a late overpressure failure of containment could occur was considered to be "certain" for all walkthroughs. The timing of power restoration is considered in question 43.

Question 37. Are fan coolers recovered late in the accident?

Surry does not have an emergency fan cooling system.

Question 38. Are the containment sprays recovered late in the accident?

As indicated in Question 36, the recovery of the containment sprays can have important effects on the progression of the accident. Recovery was evaluated on a sequence-specific basis; as a practical matter, it was credited only for sequences involving a total loss of ac power.

Question 39. Is there containment heat removal late in the accident?

The logic for this question is identical to that for question 18.

Question 40. Have the contents of the refueling water storage tank been injected into containment?

The status of this question is determined directly from the plant-damage states.

Question 41. What is the amount of water injected into the containment?

We considered the conditions under which all combinations of RWST contents, primary system contents, accumulator contents, or no water could be injected into containment. In the final version of the event tree for Surry, it was found the condition for "no water" was the only one of importance. No water is injected if the RCS blowdown bypasses containment (question 16), the RWST contents have not been injected (question 40), and the core is degraded at low pressure (question 14).

Question 42. Do significant core-concrete interactions occur after vessel breach?

Significant core-concrete interactions (i.e., those which could result in a vaporization release from the fuel) may be precluded by either of two occurrences. First, if there is a sufficient amount of water in the reactor cavity, there is a possibility that a coolable debris bed will form. Second, if there is an event which disperses the core debris, such as a high-pressure ejection or an in-vessel steam explosion which fails the reactor vessel, the core debris may be scattered so widely through the containment that significant core-concrete interactions cannot occur. Conversely, if there is insufficient water and no dispersive event, the core debris will mostly remain in the reactor cavity, the debris bed will dry out, and a core-concrete interaction will occur with a high degree of certainty.

Thorough dispersal of the ejected material was demonstrated in the HIPS tests (Ref. 28). In these tests, all melt ejected at pressures above 200 psia was widely dispersed. Even the fraction which did not finely fragment, and hence did not contribute to direct heating, was dispersed over a wide area, whether the cavity was wet or dry.

For accidents with sprays operating, ZPSS (Ref. 7) and IDCOR (Ref. 5) expected a coolable debris bed to be formed as long as water could be provided ("top-down quench"). SAUNA (Ref. 22) regarded coolability to be uncertain, because the particle size was unknown. BMI (Ref. 2) has performed calculations with and without a coolable debris bed with very different results.

The presence of water in the reactor cavity is plant-specific. At Surry, there will be water in the cavity if the sprays operate or if the accumulators discharge at the time of vessel breach. If there is a dispersive event, the debris will contact water on the containment floor provided some water has been injected into containment.

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While it is possible for a top-down quench to occur at Surry in the case of a benign meltthrough and spray operation, the uncertainty of the phenomenology and the paucity of experimental evidence led to the conclusion that top-down quench is somewhat less certain than indicated by ZPSS or IDCOR, more in line with the SAUNA estimate. We estimated the probability of prompt core-concrete interactions under these conditions to be "indeterminate" (optimistic), "likely" (central), or "almost certain" (pessimistic).

With respect to dispersive events, we expected an intermediate pressure ejection to produce moderate dispersal, and we estimated the probability of prompt core-concrete interaction to be "unlikely" for the optimistic case, with the other walkthroughs unchanged. For a high-pressure ejection or steam explosion, we expected thorough fragmentation and dispersal, and we estimated the probability of prompt core-concrete interactions to be "remotely possible" (optimistic), "unlikely" (central), or "indeterminate" (pessimistic).

If containment heat removal were not recovered or had failed, there would be no assured long-term source of water for the debris bed, and the core material could eventually dry out. In the absence of dispersion, delayed core-concrete interaction at a reduced level would be possible. It was not possible to estimate the magnitude or probability of delayed core-concrete interactions from reheating of initially cold debris.

Question 43. Is power restored before or after 6 hours?

If power had been restored soon after vessel breach, core-concrete interactions would not have produced significant quantities of hydrogen by the time containment heat removal systems had de-inerted the containment atmosphere. The hydrogen produced in-vessel would be unlikely to threaten the Surry containment except in combination with a steam spike or direct heating. On the other hand, if power were restored late in the accident, and core-concrete interactions had occurred, additional hydrogen and other combustible gases would be added to the containment atmosphere so that late hydrogen burning could be a threat to containment. The quantity of hydrogen would be dependent on the type of concrete and the chemistry of the interaction. The variability in gas production was ignored, and a break-over point of six hours was selected. For example, a calculation reported by SASA (Ref. 12) showed a possible threat to the Zion containment when power was recovered in sequence TMLB' at 397 minutes (6.6 hours), whereas no threat was observed for power recovery at 118 minutes.

The likelihood of power recovery is dependent on the specific sequence entering the containment event tree, since some recovery has already been credited for station blackout sequences. We estimated the likelihood that power would fail to be restored within 6 hours to be 0.1, based on EPRI data (Ref. 29) and on the fact that the sequences already reflect failure to restore power within 1-7 hours.

Question 44. What is the containment pressure late in the accident?

The principal sources of containment pressurization are steaming from a cooled debris bed and gases from core-concrete interaction. The pressure relieving mechanisms are containment heat removal systems and condensation and cooling at heat sinks and outer containment surfaces. The pressure within containment at any time depends quite critically on the balance between energy and gas rates to the atmosphere and the condensation and cooling rates. MARCH calculations generally show a slow upward trend in pressure, with the rate of increase being sensitive to the above-mentioned balance. In many cases, it was necessary to extrapolate pressure trends to determine late pressures. For these reasons, the estimate of pressure at 18 hours is considered to be highly uncertain. We believe that the pressures used in this analysis could be reached at some time in the accident, but the estimate of 18 hours should be understood to have wide uncertainty.

We considered six different outcomes with respect to the pressures that could be generated due to various conditions. They are as follows:

(1) Core-concrete interactions with no containment heat removal available and low condensation rates (designated as xxCC in the table of pressures below);

(2) Short-term coolable debris bed with the debris initially quenched, but with long-term cooling precluded due to the unavailability of containment heat removal and the failure of RWST water to have been injected (designated as xxST);

(3) Long-term coolable debris bed with the RWST contents injected into containment but with containment heat removal unavailable (xxLT);

(4) High natural condensation rates in containment with containment heat removal unavailable (xxHC);

(5) Containment heat removal available early or late in the accident, but not both (Ex or xL); and

(6) Containment heat removal available throughout the accident (EL).

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The corresponding base pressures for these outcomes are tabulated below. The values are shown for the optimistic, central, and pessimistic walkthroughs (probabilities are shown in parenthesis; the same values were used for optimistic, central, and pessimistic walkthroughs).

	Containment Base Pressures (psia)					
	xxCC	xxST	xxLT	xxHC	Ex/xL	EL
No containment heat removal, no coolable debris bed	(0.5)	(0.0)	(0.0)	(0.5)	(0.0)	(0.0)
	85	--	--	30	--	--
	85	--	--	40	--	--
	85	--	--	60	--	--
No containment heat removal, no RWST, coolable debris bed	(0.0)	(0.5)	(0.0)	(0.5)	(0.0)	(0.0)
	--	85	--	30	--	--
	--	85	--	40	--	--
	--	85	--	60	--	--
No containment heat removal, RWST, coolable debris bed	(0.0)	(0.0)	(1.0)	(0.0)	(0.0)	(0.0)
	--	--	160	--	--	--
	--	--	160	--	--	--
	--	--	160	--	--	--
No containment heat removal	(0.0)	(0.0)	(0.0)	(1.0)	(0.0)	(0.0)
	--	--	--	40	--	--
	--	--	--	40	--	--
	--	--	--	60	--	--
Containment heat removal, early or late	(0.0)	(0.0)	(0.0)	(0.0)	(1.0)	(0.0)
	--	--	--	--	20	--
	--	--	--	--	30	--
	--	--	--	--	40	--
Containment heat removal, early and late	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)
	--	--	--	--	--	20
	--	--	--	--	--	20
	--	--	--	--	--	20

Question 45. Has a large leak or gross failure occurred?

This question recapitulates all previous questions relating to failure or leakage (question 3, 15, 19, 22, and 31).

Question 46. Does a late hydrogen burn occur?

We consider a burn to be inevitable at some time late in the accident, provided the containment atmosphere is flammable. The conditions for flammability include adequate hydrogen, adequate oxygen, that the atmosphere not be steam inerted, and that an ignition source be present. Adequate hydrogen and other combustible gases would be present late in the accident, provided that no prior burns had occurred and the containment did not have a large leak. The same conditions ensure adequate oxygen. The containment would not be steam inert if containment heat removal systems were in operation (question 39) or if deinerting occurred (question 43). Because the atmosphere would remain flammable for many hours, we would expect some ignition source -- a spark or a particle of hot debris -- to be present at some time.

If containment heat removal does not operate late in the accident, we considered the possibility that reduced steaming rates and high natural condensation processes could deinert the atmosphere. If steam in the atmosphere were at the saturation point, combustion would be possible at approximately 25 psig. If the steam were superheated or if a large quantity of noncondensibles were present, the atmosphere could be flammable at a higher pressure. Because of the absence of firm experimental data, we took natural deinerting to be "indeterminate" for all walkthroughs.

Question 47. What pressure rise would occur if combustible gases were to burn late in the accident?

A late burn is defined as one occurring sufficiently long after vessel breach to allow virtually all of the fission products from the melt release to have settled out or been washed out by the sprays, but not necessarily late enough for the vaporization release to have been entirely depleted.

The maximum amount of hydrogen generated could exceed 100% of that due to zirconium oxidation if hydrogen due to steel oxidation or combustible gases from core-concrete interactions are included. However, the oxygen available could only burn about 150% zirconium equivalent.

IDCOR (Ref. 5) calculated a few hundred pounds of hydrogen generated for Zion. At the other end of the scale, SNLA (Ref. 18) calculated up to 2500 lb due to zircaloy oxidation, 1000 lb due to steel oxidation, and several hundred pounds from other sources, for a representative large, dry PWR.

We estimated that a late hydrogen burn could involve as much as 75% zircaloy equivalent (optimistic) or 100% zircaloy equivalent (central) or 150% zircaloy equivalent (pessimistic), if core-concrete interactions or direct heating occurred; otherwise, the amount was limited to 75% zircaloy equivalent (central) or 110% (pessimistic). If prior burns had occurred, the corresponding depletion of hydrogen and oxygen was taken into account by accordingly decreasing the size of the late burn.

The corresponding pressure increments due to a hydrogen burn are as follows:

	Optimistic Estimate	Central Estimate	Pessimistic Estimate
Core-concrete interaction, no prior burn, ac recovered after 6 hours	55	70	110
Core-concrete interaction, no prior burn, ac recovered before 6 hours	55	55	70
Neither core-concrete interaction nor direct heating, no prior burn	55	55	70
Prior hydrogen burn	0	0	0

Question 48. Would containment fail due to a late hydrogen burn or steam production?

The pressure increment from a late hydrogen burn (question 47) is added to the late containment atmosphere pressure (question 44). The mean failure pressure and standard deviation are the same as in question 22.

Question 49. In what way, if at all, does containment fail due to gradual pressurization from boiloff of water or noncondensible gases or hydrogen burning (leakage or gross rupture)?

The logic for this event is the same as for question 19.

Question 50. To what degree, if any, is the auxiliary building bypassed late in the accident?

The logic for this question is similar to that for questions 23 and 32.

Question 51. Do the fan coolers fail after the late hydrogen burn?

Surry does not have emergency fan coolers.

Question 52. Do the containment sprays fail after a late hydrogen burn?

The logic for this question is similar to that for question 34. If the sprays had not failed earlier, we considered the possibility that they could fail later, even without a hydrogen burn, due to continued pumping of debris-laden water or clogging of intake strainers. Taking into account the TAP A43 experiments, we assessed this event to be "remotely possible" (optimistic), "unlikely" (central), or "indeterminate" (pessimistic).

Question 53. Is there containment heat removal very late in the accident?

The logic for this question is identical to that for question 39.

Question 54. Is there a vaporization release?

A vaporization release may be precluded if there are no significant core-concrete interactions (question 42). A vaporization release may be mitigated if core-concrete interactions occur but the reactor cavity is water-filled, scrubbing the release. For this assessment, we assumed a vaporization release to be "certain" for all cases in which a coolable debris bed did not form, and "impossible" otherwise.

Question 55. To what degree, if any, does containment leakage due to sustained high temperatures occur very late in the accident.

We considered the potential for containment leakage late in the accident. However, it is the current understanding of the CPWG (Ref. 15) that temperature induced leakage would not be expected at Surry. This was corroborated on the basis of BMI calculations (Ref. 2), which predicted maximum atmospheric temperature of 280 F for a sequence without containment heat removal (station blackout). Elastomeric penetration seals do not begin to degrade below about 400 F.

Question 56. Does basemat meltthrough occur before containment overpressurization?

The RSS (Ref. 1) assumed that basemat meltthrough was inevitable. A race was envisioned between meltthrough, which was assumed to lead to depressurization, and overpressure failure. The ZIP study (Ref. 13) questioned whether meltthrough was either assured or likely. IDCOR (Ref. 5) stated that if half or more of the core were dispersed, core-concrete interactions would be prevented.

If core-concrete interaction occurs (question 42) there is some uncertainty as to whether the core debris will penetrate completely through the basemat. The models in core-concrete interaction codes such as CORCON are not considered to be as accurate when the core debris freezes and starts to attack the concrete as a heat-producing solid.

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If core-concrete interactions occurred, but there were an abundance of water overlying the melt, we expected that meltthrough would be delayed, and meltthrough before overpressure failure was assessed to be "unlikely". If core-concrete interaction occurred without water, meltthrough before overpressure was taken to be "indeterminate". Without core-concrete interaction, meltthrough is "impossible".

Question 57. Does containment depressurize after basemat meltthrough?

If the core debris melts through the basemat, late overpressure failure is not necessarily precluded, because pressure relief through the ground might be too slow to prevent overpressurization. Calculations in BMI-2104 assume that basemat meltthrough leads to a depressurization as a result of venting the gases through the ground, but the authors of that document recognized this to be an area of high uncertainty.

The RSS also assumed that meltthrough would depressurize the containment. However, calculations reported in the RSS indicate very slow flow out of containment, so that prompt depressurization is not assured. In the absence of overlying water, rapid depressurization given prior meltthrough is assumed to be "likely" (optimistic), "indeterminate" (central), or "unlikely" (pessimistic).

The RSS also asserted that sump water could not escape the containment. The presence of overlying water could thus act as a seal and delay depressurization. On the other hand, other studies (e.g., Ref. 30) concluded that sump water escape might be possible. With overlying water, we assumed depressurization to be "likely" (optimistic), "unlikely" (central) or "remotely possible" (pessimistic).

Question 58. What is the ultimate containment failure mode, if any, given no prior containment failure?

If there is containment heat removal or a large containment leak, long-term overpressure failure cannot occur. If, in addition, there is significant core-concrete interaction, we considered the occurrence of basemat meltthrough to be highly uncertain. Based on the information sources described in question 56, we assessed the probability of ultimate meltthrough to be "unlikely" (optimistic), "indeterminate" (central), or "likely" (pessimistic).

If meltthrough occurred and the containment depressurized, overpressure failure would be precluded, and the only possible ultimate failure mode would be meltthrough. If the containment did not depressurize, we assessed overpressure failure to be "likely" (optimistic) or "certain" (central and pessimistic). We used the same division between gross failure and large leaks as for questions 19 and 49.

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Question 59. To what degree, if any, is the auxiliary building ultimately bypassed?

The logic for this question is identical to question 50.

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TABLE B-1. EVENT DESCRIPTIONS FOR PWR SUBATMOSPHERIC AND LARGE-DRY CONTAINMENTS

	QUESTION ASKED BY EVENT TREE	PRIOR QUESTION DEPENDENCIES
1.	Is ac power available after the initiating event?	None
2.	Does core water makeup fail before containment overpressurization?	None
3.	What is the level of preexisting containment leakage or isolation failure?	1
4.	Where is the initial reactor coolant system break?	None
5.	What is the size of the initial reactor coolant system break?	None
6.	Is the containment initially bypassed?	4
7.	Are the steam generators wet or dry?	None
8.	Do the fan coolers fail to actuate before core degradation?	*
9.	Do the containment sprays fail to actuate in the injection mode before core degradation?	1,3,5,6
10.	Do the containment sprays fail to actuate in the recirculation mode before core degradation?	9
11.	To what degree, if any, is the auxiliary building initially bypassed?	3,4,7
12.	Where, if at all, is there a temperature-induced failure of the reactor coolant system during the period of core degradation?	5
13.	What is the size of the temperature-induced reactor coolant system failure?	12
14.	What is the primary system pressure during core degradation? Also, what would be the containment pressure increment from a primary system blowdown?	5,12
15.	At what level, if any, is containment bypassed during core degradation?	4,5,12,13
16.	What is the rate of blowdown to containment during core degradation?	5,6,13,15
17.	Do the containment sprays fail to actuate during the period of core degradation?	1,3,10,16
18.	Is there containment heat removal during core degradation?	8,17
19.	At what level, if any, does containment fail due to steam pressurization before vessel breach?	2,3,15,18
20.	What is the containment pressure before vessel breach?	3,16,18,19
21.	Is there a hydrogen burn before vessel breach? Also, what is the pressure increment from such a burn?	3,16,18
22.	Does containment fail because of a hydrogen burn before vessel breach? Also, what is the associated failure pressure and standard deviation?	20,21
23.	To what degree, if any, is the auxiliary building bypassed before vessel breach?	7,11,12,19,22
24.	Do the fan coolers fail after the early hydrogen burn?	*
25.	Do the containment sprays fail after the early hydrogen burn?	1,17,21,22
26.	Is there containment heat removal after the early hydrogen burn?	24,25
27.	What is the mode of reactor vessel breach?	14
28.	Does direct heating of the containment atmosphere occur just after vessel breach? Also, what is the pressure increment from a steam spike alone and from a steam spike plus direct heating?	14,17,27
29.	Is there a hydrogen burn just after vessel breach? Also, what is the pressure increment from such a burn? Also, what is the associated failure pressure and standard deviation?	3,12,21,26
30.	Does containment fail due to a steam spike, direct heating, and/or hydrogen burn just after vessel breach?	14,20,28,29
31.	What is the mode of containment failure, if any, just after vessel breach?	3,19,22,27,28 29,30.

TABLE B-1. EVENT DESCRIPTIONS FOR PWR SUBATMOSPHERIC AND LARGE-DRY CONTAINMENTS (Cont'd)

	QUESTION ASKED BY EVENT TREE	PRIOR QUESTION DEPENDENCIES
32.	To what degree, if any, is the auxiliary building bypassed just after vessel breach?	23,31
33.	Do the fan coolers fail after vessel breach?	*
34.	Do the containment sprays fail after vessel breach?	1,25,31
35.	Is there an oxidation release?	27,28
36.	Is ac power restored after vessel breach?	1
37.	Do the fan coolers fail late in the accident?	33,36
38.	Do the containment sprays fail late in the accident?	34,36
39.	Is there containment heat removal late in the accident?	37,38
40.	Has the contents of the refueling water storage tank been injected into containment?	9,17,25,34,38
41.	What is the amount of water injected into containment?	2,14,16,40
42.	Do significant core-concrete interactions occur after vessel breach?	14,18,27,34,41
43.	Is ac power recovered late in the accident?	1
44.	What is the internal pressure late in the accident?	26,39,40,42
45.	Has a large leak or gross failure occurred late in the accident?	3,15,19,22,31
46.	Does a late hydrogen burn occur?	21,29,39,44,45
47.	What pressure rise would occur if combustible gases were to burn late in the accident?	20,42,43,46
48.	Would containment fail due to a late hydrogen burn or steam production?	44,47
49.	In what way, if at all, does containment fail due to gradual pressurization from boiloff of water or noncondensible gases or hydrogen burning (leakage or gross rupture)?	45,46,48
50.	To what degree, if any, is the auxiliary building bypassed late in the accident?	32,49
51.	Do the fan coolers fail after the late hydrogen burn?	*
52.	Do the containment sprays fail after the late hydrogen burn?	38,46,49
53.	Is there containment heat removal very late in the accident?	51,52
54.	Is there a vaporization release?	17,25,34,42
55.	To what degree, if any, does containment leakage occur due to high temperatures very late in the accident?	41,45,48,53
56.	Does basemat meltthrough occur, given no prior containment failure?	26,38,39,42, 45,49,53,54,55
57.	Does containment depressurize after basemat meltthrough?	26,39,53,56
58.	What is the ultimate containment failure mode, if any, resulting from core-concrete interactions?	42,45,48,53, 55,56,57
59.	To what degree, if any, is the auxiliary building ultimately bypassed very late in the accident?	50,55,57

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*Not applicable for Surry.

Table B-2

IDENTIFICATION OF PLANT-DAMAGE STATES

Designator	Description
V(WET)	LOCA outside containment, with the break location submerged.
V(DRY)	LOCA outside containment, with the break location not submerged.
AYYB	LOCA leading to low pressure in the RCS prior to vessel breach, with RWST inventory discharged to containment; containment heat removal, spray injection, and spray recirculation are all available.
AYNI	LOCA leading to low pressure in the RCS prior to vessel breach, with RWST inventory discharged to containment; containment spray injection is available, but containment heat removal and recirculation are not functioning.
AYYR	LOCA leading to low pressure in the RCS prior to vessel breach, with RWST inventory discharged to containment; containment spray injection has failed, but containment heat removal and recirculation are available.
AYNB	LOCA leading to low pressure in the RCS, with RWST inventory discharged to containment; containment spray injection and recirculation are successful, but containment heat removal is not available. Note that this particular plant-damage state implies core melt due to the failure of containment heat removal, such that long-term overpressurization of containment prior to core melt would be expected.
AYNN	LOCA leading to low pressure in the RCS prior to vessel breach, with RWST inventory discharged to containment; the containment spray systems are not available. Note that this implies that there may be only limited water available in the reactor cavity.
S_2YYB	Small LOCA with intermediate pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment heat removal, spray injection, and spray recirculation are all available.

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Table B-2 (Continued)

IDENTIFICATION OF PLANT-DAMAGE STATES

Designator	Description
S_2YNI	Small LOCA with intermediate pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment spray injection is available, but containment heat removal and recirculation are not functioning.
S_2YYR	Small LOCA with intermediate pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment spray injection has failed, but containment heat removal and recirculation are available.
S_2YNN	Small LOCA with intermediate pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; the containment spray systems are not available. Note that this implies that there may be only limited water available in the reactor cavity.
S_2NNN	Small LOCA with intermediate pressure in the RCS prior to vessel breach; no RWST inventory is discharged to containment and the containment spray systems are not available. Note that this implies that there will be very limited water available in the reactor cavity.
S_3YYB	Very small LOCA with high pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment heat removal, spray injection, and spray recirculation are all available.
S_3YNI	Very small LOCA with high pressure in the RCS prior to vessel breach and RWST inventory discharged to containment; containment spray injection is available, but containment heat removal and recirculation are not functioning.
S_3YYR	Very small LOCA with high pressure in the RCS prior to vessel breach, and RWST inventory discharged to containment; containment spray injection has failed, but spray recirculation and containment heat removal are available.
S_3YNN	Very small LOCA with high pressure in the RCS prior to vessel breach, and RWST inventory discharged to containment; the containment spray

Table B-2 (Continued)

IDENTIFICATION OF PLANT-DAMAGE STATES

Designator	Description
	systems are not available. Note that this implies that there may be only limited water available in the reactor cavity.
S_3NNN	Very small LOCA with high pressure in the RCS prior to vessel breach; no RWST inventory is discharged to containment and the containment spray systems are not available. Note that this implies that there will be very limited water available in the reactor cavity.
TYYB	Intact RCS prior to vessel breach, with RWST inventory discharged to containment; containment heat removal, spray injection, and spray recirculation are all available.
TYNI	Intact RCS prior to vessel breach, with RWST inventory discharged to containment; containment spray injection is available, but containment heat removal and recirculation are not functioning.
TYYR	Intact RCS prior to vessel breach, with RWST inventory discharged to containment; spray injection has failed, but containment heat removal and recirculation are available.
TYNN	Intact RCS prior to vessel breach, with RWST inventory discharged to containment; the containment spray systems not available. Note that this implies that there may be only limited water available in the reactor cavity.
TNNN	Intact RCS prior to vessel breach, with no RWST inventory discharged to containment and the containment spray systems are not available. Note that this implies that there will be very limited water available in the reactor cavity.

Appendix C

CONTAINMENT EVENT TREE COMPUTER INPUT FOR THE SURRY PLANT

The actual computer input for the analysis of the response of the Surry containment to postulated core-melt accidents is displayed on the following pages. The input format is the same as that described in Appendix A of this report. The input is presented for one plant damage state, TYYB, but the questions which change depending on the damage state being modeled are clearly indicated. Due to code input limitations, the outcomes of various questions are designated by short descriptions. The actual meanings of the outcomes designated by these descriptors are defined in Appendix B.

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SURRY CONTAINMENT EVENT TREE

Note: The tree below is setup for a core-melt plant damage state involving a transient without a LOCA in the primary system and with the availability of offsite and onsite power. The event tree requires some changes to model other core-melt damage states. Those questions that are dependent on the damage state being modeled are preceeded by a "*".

```
   3      1.0      1.0      1.0       59          1.0E-4         1.0E-7
 Nwal   Pinit    Pinit    Pinit   Nquest          Prntol          Toler
*1 Is there early failure of AC power?
   2     E-AC     EfAC
   1        1        2
        1.000    0.000
        1.000    0.000
        1.000    0.000
*2 Does ECC fail prior to containment overpressure?
   2    EfECC    DfECC
   1        1        2
        1.000    0.000
        1.000    0.000
        1.000    0.000
3 Is there pre-existing leakage or isolation failure?
   4      EE3      EE2      EE1      EE0
   2        1        2        3        4
   2
   1        1
            2
         EfAC
      0.0000   0.0000   0.0130   0.9870
      0.0000   0.0020   0.0280   0.9700
      0.0000   0.0020   0.0510   0.9470
    Otherwise
      0.0000   0.0000   0.0130   0.9870
      0.0000   0.0020   0.0280   0.9700
      0.0000   0.0020   0.0510   0.9470
*4 Where is initial break location in the primary?
   6      RPV       HL       CL     SGTR        V     PORV
   1        1        2        3        4        5        6
        0.000    0.000    0.000    0.000    0.000    1.000
        0.000    0.000    0.000    0.000    0.000    1.000
        0.000    0.000    0.000    0.000    0.000    1.000
*5 Initial break size
   5     LgBk     SmBk       S1       S2       S3
   1        1        2        3        4        5
        0.000    0.000    0.000    0.000    1.000
        0.000    0.000    0.000    0.000    1.000
        0.000    0.000    0.000    0.000    1.000
6 Initial containment bypass?
   2      EEB    noEEB
   2        1        2
   2
   4        4        4        4        4
           -1       -2       -3       -6
        noRPV     noHL     noCL   noPORV
        1.000    0.000
        1.000    0.000
        1.000    0.000
        Otherwise
           0.000   1.000
           0.000   1.000
           0.000   1.000
    *7 Steam Generators wet or dry?
        2    SGwet   SGdry
        1        1       2
           1.000   0.000
           1.000   0.000
           1.000   0.000
    8 Initial fan cooler operation?
 Note: Surry does not have fan coolers
        2     EEFC  noEEFC
        2        1       2
        2
        1        1
                 2
           EfAC
           0.000   1.000
           0.000   1.000
           0.000   1.000
           Other
           0.000   1.000
           0.000   1.000
           0.000   1.000
    9 Do the sprays operate in the injection mode ?
        3     EESp   EEaSp   EEfSp
        2        1       2       3
        4
        3        1       3       5
                 1      -1       1
           E-AC    NoEE3    LgBk
           1.000   0.000   0.000
           1.000   0.000   0.000
           1.000   0.000   0.000
        5        1       3       3        6       8
                 1      -1      -2        2       2
           E-AC    noEE3   noEE2   noEEB NOEEFC
           1.000   0.000   0.000
           1.000   0.000   0.000
           1.000   0.000   0.000
        4        1       3       5        6
                 1       2       2        2
           E-AC      EE2    ImBk   noEEB
           1.000   0.000   0.000
           1.000   0.000   0.000
           1.000   0.000   0.000
        Otherwise
           0.000   1.000   0.000
           0.000   1.000   0.000
           0.000   1.000   0.000
   *10 Do sprays operate in the recirculation mode ?
        3     EESp   EEaSp   EEfSp
        2        1       2       3
        3
        1        9
                 1
        EESpInj
           1.000   0.000   0.000
           1.000   0.000   0.000
```

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         1.000    0.000    0.000
   1         9
             2
      EEaSpInj
         0.000    1.000    0.000
         0.000    1.000    0.000
         0.000    1.000    0.000
      Otherwise
         0.000    0.000    1.000
         0.000    0.000    1.000
         0.000    0.000    1.000
11 Degree of auxiliary building bypass?
   3     EESB3    EESB2    EESB1
   2         1        2        3
   5
   3         3        4        4
            -4       -4       -5
         noEEO  noSGTR      noV
         0.000    0.100    0.900
         0.000    0.100    0.900
         0.000    0.100    0.900
   2         4        7
             4        1
          SGTR    SGWet
         0.000    0.100    0.900
         0.000    0.100    0.900
         0.000    0.100    0.900
   2         4        7
             4        2
          SGTR    SGDry
         1.000    0.000    0.000
         1.000    0.000    0.000
         1.000    0.000    0.000
   1         4
             5
             V
         0.000    0.100    0.900
         0.000    0.100    0.900
         0.000    0.100    0.900
      Otherwise
         0.000    0.000    1.000
         0.000    0.000    1.000
         0.000    0.000    1.000
12 Location of induced failure in primary system?
   5     EfRPV     EfHL     EfCL    ESGTR noEfRCPB
   2         1        2        3        4        5
   3
   2         5        7
             5        2
            S3    SGDRY
         0.000    0.100    0.900    0.000    0.000
         0.000    0.250    0.250    0.001    0.499
         0.000    0.000    0.100    0.100    0.800
   2         5        7
             5        1
            S3    SGWET
         0.000    0.100    0.900    0.000    0.000
         0.000    0.250    0.250    0.000    0.500
         0.000    0.000    0.100    0.500    0.300
      Otherwise
```

```
          0.000     0.000     0.000     0.000     1.000
          0.000     0.000     0.000     0.000     1.000
          0.000     0.000     0.000     0.000     1.000
13 Area of Temperature-induced primary system failure
    5     ELgBk     EImBk       ES1       ES2  noEfRCPB
    2         1         2         3         4         5
    5
    1        12
              1
          EfRPV
          1.000     0.000     0.000     0.000     0.000
          1.000     0.000     0.000     0.000     0.000
          1.000     0.000     0.000     0.000     0.000
    1        12
              2
           EfHL
          1.000     0.000     0.000     0.000     0.000
          1.000     0.000     0.000     0.000     0.000
          1.000     0.000     0.000     0.000     0.000
    1        12
              3
           EfCL
          0.000     0.000     0.000     1.000     0.000
          0.000     0.000     0.000     1.000     0.000
          0.000     0.000     0.000     1.000     0.000
    1        12
              4
          ESGTR
          0.000     0.000     0.000     1.000     0.000
          0.000     0.000     0.000     1.000     0.000
          0.000     0.000     0.000     1.000     0.000
       Otherwise
          0.000     0.000     0.000     0.000     1.000
          0.000     0.000     0.000     0.000     1.000
          0.000     0.000     0.000     0.000     1.000
14 Primary system pressure during core degradation
    3       HiP       ImP       LoP
    4         1         2         3
    4
    2         5        12
              5         5
             S3  noEfRCPB
          1.000     0.000     0.000
          1.000     0.000     0.000
          1.000     0.000     0.000
    1
    1      15.0       7.0       0.0
           15.0       7.0       0.0
           15.0       7.0       0.0 Pressure rise due to primary depressurization
    2         5        12
              4         5
             S2  noEfRCPB
          0.000     1.000     0.000
          0.000     1.000     0.000
          0.000     1.000     0.000
    1
    1      15.0       7.0       0.0
           15.0       7.0       0.0
           15.0       7.0       0.0 Pressure rise due to primary depressurization
    1        13
```

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```
              4
            ES2
          0.000   1.000   0.000
          0.000   1.000   0.000
          0.000   1.000   0.000
      1
      1    15.0     7.0     0.0
           15.0     7.0     0.0
           15.0     7.0     0.0 Pressure rise due to primary depressurization
       Otherwise
          0.000   0.000   1.000
          0.000   0.000   1.000
          0.000   0.000   1.000
      1
      1    15.0     7.0     0.0
           15.0     7.0     0.0
           15.0     7.0     0.0 Pressure rise due to primary depressurization
15 Early containment bypass (during meltdown)?
      3     EB2     EB1    noEB
      2       1       2       3
      5
      8       4       4       4       4       5       5       5      12
             -1      -2      -3      -6      -1      -2      -3       5
          noRPV    noHL    noCL  noPORV    noLg    noIm    noS1 noEfRCPB
          0.000   1.000   0.000
          0.000   1.000   0.000
          0.000   1.000   0.000
      7       4       4       4       4       5       5      12
             -1      -2      -3      -6      -4      -5       5
          noRPV    noHL    noCL  noPORV    noS2    noS3 noEfRCPB
          1.000   0.000   0.000
          1.000   0.000   0.000
          1.000   0.000   0.000
      2      12      13
              4       4
          ESGTR     ES2
          0.000   1.000   0.000
          0.000   1.000   0.000
          0.000   1.000   0.000
      3      12      13      13
              4      -4      -5
          ESGTR   noES2  EfRCPB
          1.000   0.000   0.000
          1.000   0.000   0.000
          1.000   0.000   0.000
       Otherwise
          0.000   0.000   1.000
          0.000   0.000   1.000
          0.000   0.000   1.000
16 Maximum rate of blowdown to containment.
      6      Lg      Im      S1      S2      S3    None
      2       1       2       3       4       5       6
     10
      2       5       6
              1       2
           LgBk   noEEB
          1.000   0.000   0.000   0.000   0.000   0.000
          1.000   0.000   0.000   0.000   0.000   0.000
          1.000   0.000   0.000   0.000   0.000   0.000
      2       5       6
```

```
             2         2
          ImBk     noEEB
         0.000     1.000     0.000     0.000     0.000     0.000
         0.000     1.000     0.000     0.000     0.000     0.000
         0.000     1.000     0.000     0.000     0.000     0.000
   2         5         6
             3         2
            S1     noEEB
         0.000     0.000     1.000     0.000     0.000     0.000
         0.000     0.000     1.000     0.000     0.000     0.000
         0.000     0.000     1.000     0.000     0.000     0.000
   2         5         6
             4         2
            S2     noEEB
         0.000     0.000     0.000     1.000     0.000     0.000
         0.000     0.000     0.000     1.000     0.000     0.000
         0.000     0.000     0.000     1.000     0.000     0.000
   4         5         6        13        15
             5         2         1         3
            S3     noEEB     ELgBk      noEB
         1.000     0.000     0.000     0.000     0.000     0.000
         1.000     0.000     0.000     0.000     0.000     0.000
         1.000     0.000     0.000     0.000     0.000     0.000
   4         5         6        13        15
             5         2         2         3
            S3     noEEB     EImBk      noEB
         0.000     1.000     0.000     0.000     0.000     0.000
         0.000     1.000     0.000     0.000     0.000     0.000
         0.000     1.000     0.000     0.000     0.000     0.000
   4         5         6        13        15
             5         2         3         3
            S3     noEEB       ES1      noEB
         0.000     0.000     1.000     0.000     0.000     0.000
         0.000     0.000     1.000     0.000     0.000     0.000
         0.000     0.000     1.000     0.000     0.000     0.000
   4         5         6        13        13
             5         2         4         3
            S3     noEEB       ES2      noEB
         0.000     0.000     0.000     1.000     0.000     0.000
         0.000     0.000     0.000     1.000     0.000     0.000
         0.000     0.000     0.000     1.000     0.000     0.000
   3         5         6        15
             5         2         3
            S3     noEEB      noEB
         0.000     0.000     0.000     0.000     1.000     0.000
         0.000     0.000     0.000     0.000     1.000     0.000
         0.000     0.000     0.000     0.000     1.000     0.000
      Otherwise
         0.000     0.000     0.000     0.000     0.000     1.000
         0.000     0.000     0.000     0.000     0.000     1.000
         0.000     0.000     0.000     0.000     0.000     1.000
17 Do the sprays come on after the induced LOCA?
   3       ESp      FaSp      EfSp
   2         1         2         3
   9
   1        10
             1
          EESp
         1.000     0.000     0.000
         1.000     0.000     0.000
```

```
           1.000     0.000     0.000
     4         1         3        10        16
               1         2         2         1
            E-AC       EE2     EEaSp      LgBk
           1.000     0.000     0.000
           1.000     0.000     0.000
           1.000     0.000     0.000
     4         1         3        10        16
               1         2         2         2
            E-AC       EE2     EEaSp      ImBk
           0.900     0.100     0.000
           0.900     0.100     0.000
           0.900     0.100     0.000
     5         1         3         3        10        16
               1        -1        -2         2         1
            E-AC     noEE3     noEE2     EEaSp      LgBk
           1.000     0.000     0.000
           1.000     0.000     0.000
           1.000     0.000     0.000
     5         1         3         3        10        16
               1        -1        -2         2         2
            E-AC     noEE3     noEE2     EEaSp      ImBk
           1.000     0.000     0.000
           1.000     0.000     0.000
           1.000     0.000     0.000
     7         1         3         3         8        10        16        16
               1        -1        -2         1         2        -5        -6
            E-AC     noEE3     noEE2      EEFC     EEaSp     NotE3    NoNone
           0.900     0.100     0.000
           0.900     0.100     0.000
           0.900     0.100     0.000
     2         1        10
               2         2
            EfAC     EEaSp
           0.000     1.000     0.000
           0.000     1.000     0.000
           0.000     1.000     0.000
     1        10
               3
           EEfSp
           0.000     0.000     1.000
           0.000     0.000     1.000
           0.000     0.000     1.000
         Otherwise
           0.000     1.000     0.000
           0.000     1.000     0.000
           0.000     1.000     0.000
18 Early containment heat removal?
     2      ECHR    noECHR
     2         1         2
     2
     2         8        17
               2        -1
          noEEFC     noESp
           0.000     1.000
           0.000     1.000
           0.000     1.000
         Otherwise
           1.000     0.000
           1.000     0.000
```

```
        1.000   0.000
19 Early containment failure due to steam buildup (EP)?
     3      EP3       EP2     noEP
     2        1         2        3
     2
     5        2         2        3        15        18
              2        -1       -2        -3         2
        DfECC     noEE3    noEE2      noEB    noECHR
        0.100     0.900    0.000
        0.999     0.001    0.000
        0.999     0.001    0.000
      Otherwise
        0.000     0.000    1.000
        0.000     0.000    1.000
        0.000     0.000    1.000
20 Baseline pressure prior to vessel breach
     1    Pbase
     4        1
     5
     4        3         3       16        18
             -1        -2       -6         1
        noEE3     noEE2 Blowdown      ECHR
        1.000
        1.000
        1.000
     1
     2     20.0
           30.0
           20.0
     5        3         3       16        18        19
             -1        -2       -6         2         3
        noEE3     noEE2 Blowdown noECHR        noEP
        1.000
        1.000
        1.000
     1
     2     40.0
           40.0
           40.0
     3        3        16       18
              2        -6        1
            EE2  Blowdown     ECHR
        1.000
        1.000
        1.000
     1
     2     15.0
           15.0
           15.0
     3        3        16       18
              2        -6        2
            EE2  Blowdown   noECHR
        1.000
        1.000
        1.000
     1
     2     20.0
           20.0
           20.0
      Otherwise
```

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```
         1.090
         1.000
         1.000
     1
     2    14.7
          14.7
          14.7
21 Hydrogen burn before vessel breach?
     2     EHB   noEHB
     4       1       2
     6
     7       3       3      16      16      16      16      18
            -1      -2      -3      -4      -5      -6       1
         noEE3   noEE2    noS1    noS2    noS3    Some    ECHR
         0.000   1.000
         0.100   0.900
         0.100   0.900
     1
     3     0.0     0.0
          25.0     0.0
          50.0     0.0 Pressure rise due to H2 burn
     4       3       3      16      18
            -1      -2       3       1
         noEE3   noEE2      S1    ECHR
         0.000   1.000
         0.000   1.000
         0.100   0.900
     1
     3     0.0     0.0
           0.0     0.0
          35.0     0.0 Pressure rise due to H2 burn
     7       3       3      16      16      16      16      18
            -1      -2      -1      -2      -3      -6       1
         noEE3   noEE2    noLq    noIa    noS1    some    ECHR
         0.000   1.000
         0.000   1.000
         0.000   1.000
     1
     3     0.0     0.0
           0.0     0.0
           0.0     0.0 Pressure rise due to H2 burn
     6       3      16      16      16      16      18
             2      -3      -4      -5      -6       1
           EE2    noS1    noS2    noS3    Some    ECHR
         0.000   1.000
         0.000   1.000
         0.100   0.900
     1
     3     0.0     0.0
           0.0     0.0
          35.0     0.0 Pressure rise due to H2 burn
     3       3      16      18
             2       3       1
           EE2      S1    ECHR
         0.000   1.000
         0.000   1.000
         0.100   0.900
     1
     3     0.0     0.0
           0.0     0.0
```

```
       25.0     0.6 Pressure rise due to H2 burn
     Otherwise
       0.000   1.000
       0.900   1.000
       0.000   1.000
   1
   3     0.0     6.0
         0.0     0.0
         0.0     0.0 Pressure rise due to H2 burn
22 Does containment fail due to an early hydrogen burn ?
   2        EH   noEH
   5         1      2
   2         2      3
       PBase PH2Burn
     'AND'
     'NORMAL'       2   134.0      2.5
                        134.0     15.0
                        100.0     15.0
                  CFP    MEAN    SIGMA
23 Early auxiliary building bypass
   3      ESB3     ESB2     ESB1
   2         1        2        3
   9
   1        11
             1
        EESB3
        1.000    0.000    0.000
        1.000    0.000    0.000
        1.000    0.000    0.000
   3        11       19       22
             2        3        2
        EESB2      EP1     NoEH
        0.000    1.000    0.000
        0.000    1.000    0.000
        0.000    1.000    0.000
   3        11       19       22
             2        1        2
        EESB2      EP2     NoEH
        0.000    1.000    0.000
        0.001    0.998    0.000
        0.100    0.900    0.000
   2        11       19
            -1        1
      noEESB3      EP3
        0.900    0.100    0.000
        0.999    0.001    0.000
        1.000    0.000    0.000
   2        11       22
            -1        1
      NoEESB3       EH
        0.900    0.100    0.000
        0.999    0.001    0.000
        1.000    0.000    0.000
   3        11       19       22
             3        2        2
        EESB1      EP2     NoEH
        0.000    0.100    0.900
        0.001    0.500    0.499
        0.100    0.810    0.090
   3        11       12        7
```

```
                3          4          1
            RRSR1      RSGTR      SGWet
            0.000      0.100      0.900
            0.000      0.100      0.900
            0.000      0.100      0.900
      2        12          7
                4          2
            RSGTR      SGDry
            1.000      0.000      0.000
            1.000      0.000      0.900
            1.000      0.900      0.000
          Otherwise
            0.000      0.000      1.000
            0.000      0.000      1.000
            0.000      0.000      1.000
24 Fan coolers on after hydrogen burn?
      3       EFC       EaFC       EfFC
      2         1          2          3
      4
      2         8         21
                1          1
             EEFC        EHB
            0.000      0.000      1.000
            0.000      0.000      1.000
            0.000      0.000      1.000
      2         8         21
                2          1
           noEEFC        EHB
            0.000      0.000      1.000
            0.000      0.000      1.000
            0.000      0.000      1.000
      2         8         21
                1          2
             EEFC      noEHB
            0.000      0.000      1.000
            0.000      0.000      1.000
            0.000      0.000      1.000
          Otherwise
            0.000      0.000      1.000
            0.000      0.000      1.000
            0.000      0.000      1.000
25 Sprays on after hydrogen burn?
      3       ESp       EaSp       EfSp
      2         1          2          3
      9
      3        17         21         22
                1          1          2
              ESp        EHB       noEH
            0.999      0.000      0.001
            9.999      0.000      0.001
            0.999      0.000      0.001
      2        17         22
                1          1
              ESp         EH
            0.900      0.000      0.100
            0.900      0.000      0.100
            0.100      0.000      0.900
      4         1         17         21         22
                1          2          1          2
             E-AC       EaSp        EHB       noEH
```

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```
           0.999     0.000     0.001
           0.999     0.000     0.001
           0.999     0.000     0.001
     3         1        17        22
               1         2         1
            E-AC      RnSp        RH
           0.900     0.000     0.100
           0.900     0.000     0.100
           0.100     0.000     0.900
     2        17        21
               1         2
            RRSp     noCHB
           1.000     0.000     0.000
           1.000     0.000     0.000
           1.000     0.000     0.000
     2        17        21
               2         2
           RRaSp     noCHB
           0.000     1.000     0.000
           0.000     1.000     0.000
           0.000     1.000     0.000
     3         1        17        22
               2         2         1
            RfAC      RaSp        RJ
           0.000     0.999     0.001
           0.000     0.900     0.100
           0.000     0.100     0.900
     4         1        17        21        22
               2         2         1         2
            RfAC      RaSp       RHB      noRH
           0.000     1.000     0.000
           0.000     1.000     0.000
           0.000     0.999     0.001
       Otherwise
           0.000     0.000     1.000
           0.000     0.000     1.000
           0.000     0.000     1.000
26 Early containment heat removal
     2      ECHR   noECHR
     2         1        2
     2
     2        24       25
              -1       -1
           noEFC    noESp
           0.000    1.000
           0.000    1.000
           0.000    1.000
       Otherwise
           1.000    0.000
           1.000    0.000
           1.000    0.000
27 Mode of vessel breach
     5     alpha    SE-UH    SE-BH       VEj          H
     2         1        2        3         4          5
     3
     1        14
               1
             HiP
          0.0000   0.0000   0.0000    1.0000     0.0000
          0.0001   0.0000   0.2100    0.7899     0.0000
```

```
      0.1000  0.0000  0.4000  0.5000  0.0000
 1        14
           2
         ImP
      0.0000  0.0000  0.0000  1.0000  0.0000
      0.0001  0.0000  0.2100  0.7899  0.0000
      0.1000  0.0000  0.4000  0.5000  0.0000
         LoP
      0.0000  0.0000  0.0000  0.0000  1.0000
      0.0001  0.0000  0.2100  0.0000  0.7899
      0.1000  0.0000  0.4000  0.0000  0.5000
28 Does direct heating occur in conjuction with steam spike?
 2        DH    noDH
 4         1       2
 0
 1        27
           2
       SE-DH
       0.000   1.000
       0.000   1.000
       0.000   1.000
 1
 4      11.0    11.0
        44.0    15.0
       104.0    26.0
 4        14      27      27      17
           1      -1      -3      -1
         HiP NoAlpha  NoSEDH   NoESp
       0.000   1.000
       1.000   0.000
       1.000   0.000
 1
 4      11.0    11.0
        44.0    15.0
       104.0    26.0
 4        14      27      27      17
           1      -1      -3       1
         HiP NoAlpha  NoSEDH     ESp
       0.000   1.000
       1.000   0.000
       1.000   0.000
 1
 4      11.0    11.0
        25.0    15.0
        57.0    26.0
 4        14      27      27      17
           2      -1      -3       1
         ImP NoAlpha  NoSEDH     ESp
       0.000   1.000
       1.000   0.000
       1.000   0.000
 1
 4      11.0    11.0
        20.0    15.0
        41.0    26.0
 4        14      27      27      17
           2      -1      -3      -1
         ImP NoAlpha  NoSEDH   NoESp
       0.000   1.000
       1.000   0.000
      1.000   0.000
 1
 6      0.0     0.0
       19.0     2.0
       43.0     4.0
 3       14      27       17
          3      -1        1
        LoP NoAlpha      HSp
      0.000   1.000
      0.000   1.000
      0.000   1.000
 1
 4     11.0    11.0
       15.0    15.0
       26.0    26.0
 3       14      27       17
          3      -1       -1
        LoP NoAlpha    NoHSp
      0.000   1.000
      0.000   1.000
      0.000   1.000
 1
 4      0.0     0.0
        2.0     2.0
        4.0     4.0
   Otherwise
      0.000   1.000
      0.000   1.000
      0.000   1.000
 1
 4     11.0    11.0
       15.0    15.0
       26.0    26.0
29 Hydrogen burn at VB
 2    HB@VB noHB@VB
 4        1       2
11
 8        3       3       16       16       16       16       21       26
         -1      -2       -3       -4       -5       -6        1        1
      noEE3   noEE2     noG1     noG2     noG3   nonone      EHB     ECHR
      0.000   1.000
      0.000   1.000
      0.000   1.000
 1
 5      0.0     0.0
        0.0     0.0
        0.0     0.0
 5        3       3       16       21       26
         -1      -2        3        1        1
      noEE3   noEE2       G1      EHB     ECHR
      0.000   1.000
      0.000   1.000
      0.900   0.100
 1
 8      0.0     0.0
        0.0     0.0
       30.0     0.0
 8        3       3       16       16       16       16       21       26
         -1      -2       -1       -2       -3       -6        1        1
      noEE3   noEE2     noLg     noIn     noG1   nonone      EHB     ECHR
```

```
         0.000     1.000
         0.000     1.000
         0.000     1.000
   1
   5       0.0       0.0
           0.0       0.0
           0.0       0.0
   5         2         3        16        21        26
            -1        -2        -6         2         1
        noEE3     noEE2    nonone    noEMB      ECHR
         0.900     0.100
         0.900     0.100
         0.900     0.100
   1
   5      25.0       0.0
          35.0       0.0
          70.0       0.0
   7         3        16        16        16        16        21        26
             2        -3        -4        -5        -6         1         1
           EE2      noS1      noS2      noS3    nonone       EMB      ECHR
         0.000     1.000
         0.000     1.000
         0.000     1.000
   1
   5       0.0       0.0
           0.0       0.0
           0.0       0.0
   4         3        16        21        26
             2         3         1         1
           EE2        S1       EMB      ECHR
         0.000     1.000
         0.000     1.000
         0.900     0.100
   1
   5       0.0       0.0
           0.0       0.0
          35.0       0.0
   7         3        16        16        16        16        21        26
             2        -1        -2        -3        -6         1         1
           EE2      noLg      noIm      noS1    nonone       EMB      ECHR
         0.000     1.000
         0.000     1.000
         0.000     1.000
   1
   5       0.0       0.0
           0.0       0.0
           0.0       0.0
   7         3        16        16        16        16        21        26
             2        -3        -4        -5        -6         2         1
           EE2      noS1      noS2      noS3    nonone     noEMB      ECHR
         0.000     1.000
         0.900     0.100
         0.900     0.100
   1
   5       0.0       0.0
          25.0       0.0
          55.0       0.0
   4         3        16        21        26
             2         3         2         1
           EE2        S1     noEMB      ECHR
          0.000    1.000
          0.900    0.100
          0.900    0.100
     1
     5      0.0      0.0
           25.0      0.0
           45.0      0.0
     7        3       16       26       16       16       21       26
              2       -1       -2       -3       -6        2        1
            EH2     noIg     noIm     noSl   nonone    noEHB     ECHR
          0.000    1.000
          0.900    0.100
          0.900    0.100
     1
     5      0.0      0.0
           35.0      0.0
           65.0      0.0
       Otherwise
          0.000    1.000
          0.000    1.000
          0.000    1.000
     1
     5      0.0      0.0
            6.0      0.0
            0.0      0.0
 30 Containment failure due to SE, DH, &/or hb @ VB ?
     2    CF@VB  noCF@VB
     5        1        2
     4        1        2        4        5
           PVMP    Pbase      PDS      PE2
          'AND'
       'NORMAL'        3    136.0      2.5
                            134.0     15.0
                            100.0     15.0
                     CFP     MEAN    SIGMA
 31 What is the mode of containment failure at or following vessel breach?
     5       IA       ID      IBS       IB    noICF
     2        1        2        3        4        5
     5
     1       27
              1
             IA
          1.000    0.000    0.000    0.000    0.000
          1.000    0.000    0.000    0.000    0.000
          1.000    0.000    0.000    0.000    0.000
     6        3       19       22       27       28       30
             -1       -1        2       -1        1        1
          noEH3    noEP3     noEH     noIA       DH      ICF
          0.000    1.000    0.000    0.000    0.000
          0.000    1.000    0.000    0.000    0.000
          0.000    1.000    0.000    0.000    0.000
     7        3       19       22       27       28       29       30
             -1       -1        2       -1        2        1        1
          noEH3    noEP3     noEH     noIA     noDH    HB@VB      ICF
          0.000    0.000    1.000    0.000    0.000
          0.000    0.000    1.000    0.000    0.000
          0.000    0.000    1.000    0.000    0.000
     7        3       19       22       27       28       29       30
             -1       -1        2       -1        2        2        1
          noEH3    noEP3     noEH     noIA     noDH  noHb@VB      ICF
```

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```
            0.000    0.000    0.000    1.000    0.000
            0.000    0.000    0.000    1.000    0.000
            0.000    0.000    0.000    1.000    0.000
          Otherwise
            0.000    0.000    0.000    0.000    1.000
            0.000    0.000    0.000    0.000    1.000
            0.000    0.000    0.000    0.000    1.000
 32 Degree of intermediate auxiliary building bypass ?
     3      ISB3     ISB2     ISB1
     2         1        2        3
     5
     1        23
               1
            ESB3
           1.000    0.000    0.000
           1.000    0.000    0.000
           1.000    0.000    0.000
     1        31
               1
              IA
           1.000    0.000    0.000
           1.000    0.000    0.000
           1.000    0.000    0.000
     2        31       31
              -1       -5
            noIA      ICF
           0.900    0.100    0.000
           0.999    0.001    0.000
           1.000    0.000    0.000
     2        23       31
               2        5
            ESB2    noICF
           0.000    1.000    0.000
           0.000    1.000    0.000
           0.000    1.000    0.000
         Otherwise
           0.000    0.000    1.000
           0.000    0.000    1.000
           0.000    0.000    1.000
 33 Fan coolers operating after vessel breach?
     3       IFC     IaFC     IfFC
     2         1        2        3
     7
     2        24       28
               1        1
             EFC       DH
           0.000    0.000    1.000
           0.000    0.000    1.000
           0.000    0.000    1.000
     2        24       29
               1        1
             EFC    HB@VB
           0.000    0.000    1.000
           0.000    0.000    1.000
           0.000    0.000    1.000
     3        24       28       29
               1        2        2
             EFC     noDH noHB@VB
           0.000    0.000    1.000
           0.000    0.000    1.000
           0.000     0.000     1.000
   2          24        28
               2         1
            EaFC        DH
           0.000     0.000     1.000
           0.000     0.000     1.000
           0.000     0.000     1.000
   2          24        29
               2         1
            EaFC     HB@VB
           0.000     0.000     1.000
           0.000     0.000     1.000
           0.000     0.000     1.000
   3          24        28        29
               2         2         2
            EaFC      noDH   noHB@VB
           0.000     0.000     1.000
           0.000     0.000     1.000
           0.000     0.000     1.000
       Otherwise
           0.000     0.000     1.000
           0.000     0.000     1.000
           0.000     0.000     1.000
34 Sprays operate after vessel breach?
   3         ISp      IaSp      IfSp
   2           1         2         3
   7
   2          25        31
               1         5
             ESp     noICF
           0.999     0.000     0.001
           0.900     0.000     0.100
           0.500     0.000     0.500
   3          25        31        31
               1        -1        -5
             ESp      noIA       ICF
           0.900     0.000     0.100
           0.900     0.000     0.100
           0.500     0.000     0.500
   3           1        25        31
               1         2         5
            E-AC      EaSp     noICF
           0.999     0.000     0.001
           0.900     0.000     0.100
           0.500     0.000     0.500
   3           1        25        31
               2         2         5
            EfAC      EaSp     noICF
           0.000     0.999     0.001
           0.000     0.900     0.100
           0.000     0.500     0.500
   4           1        25        31        31
               1         2        -1        -5
            E-AC      EaSp      noIA       ICF
           0.900     0.000     0.100
           0.900     0.000     0.100
           0.500     0.000     0.500
   4           1        25        31        31
               2         2        -1        -5
            EfAC      EaSp      noIA       ICF
```

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```
        0.000    0.999    0.001
        0.000    0.900    0.100
        0.000    0.500    0.500
      Otherwise
        0.000    0.000    1.000
        0.000    0.000    1.000
        0.000    0.000    1.000
35 Is there an oxidation release?
    2        Ox     noOx
    2         1        2
    3
    1        28
              1
             DH
        1.000    0.000
        1.000    0.000
        1.000    0.000
    2        27       27
             -4       -5
        noPBj      ncM
        1.000    0.000
        1.000    0.000
        1.000    0.000
      Otherwise
        0.000    1.000
        0.000    1.000
        0.000    1.000
36 Is AC power restored after vessel breach?
    2      L-AC     LfAC
    2         1        2
    2
    1         1
              1
           E-AC
        1.000    0.000
        1.000    0.000
        1.000    0.000
      Otherwise
        1.000    0.000
        1.000    0.000
        1.000    0.000
37 Do the fan coolers operate late?
    3       LFC     LaFC     LfFC
    2         1        2        3
    4
    1        33
              3
           IfFC
        0.000    0.000    1.000
        0.000    0.000    1.000
        0.000    0.000    1.000
    2        33       36
              2        1
           IaFC     L-AC
        0.000    0.000    1.000
        0.000    0.000    1.000
        0.000    0.000    1.000
    2        33       36
              2        2
           IaFC  noL-AC
```

```
          0.000     0.000     1.000
          0.000     0.000     1.000
          0.000     0.000     1.000
        Otherwise
          0.000     0.000     1.000
          0.000     0.000     1.000
          0.000     0.000     1.000
38 Do sprays operate late in the scenario?
     3       ISp      LaSp      LfSp
     2         1         2         3
     4
     1        34
               3
           EfSp
          0.000     0.000     1.000
          0.000     0.000     1.000
          0.000     0.000     1.000
     2        34        36
               3         1
           IaSp      I-AC
          1.000     0.000     0.000
          1.000     0.000     0.000
          1.000     0.000     0.000
     2        34        36
               2         2
           IaSp    noI-AC
          0.000     1.000     0.000
          0.000     1.000     0.000
          0.000     1.000     0.000
        Otherwise
          1.000     0.000     0.000
          1.000     0.000     0.000
          1.000     0.000     0.000
39 Late containment heat removal
     2      LCHR    noLCHR
     2         1         2
     2
     2        37        38
              -1        -1
          noLFC     noLSp
          0.000     1.000
          0.000     1.000
          0.000     1.000
        Otherwise
          1.000     0.000
          1.000     0.000
          1.000     0.000
*40 Has the RWST been injected into the containment?
     2     SpInj  noSpInj
     2         1         2
     2
     5         9        17        25        34        38
              -1        -1        -1        -1        -1
        noEESp     noESp     noESp     noISp     noLSp
          0.000     1.000
          0.000     1.000
          0.000     1.000
        Otherwise
          1.000     0.000
          1.000     0.000
```

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```
             1.000     0.000
41 Amount of water injected into containment?
       6     R+A+P       R+A       A+P         R         A      none
       2         1         2         3         4         5         6
       6
       3        14        16        40
                -3         6         1
             notLP      noBD     SpInj
             0.000     1.000     0.000     0.000     0.000     0.000
             0.000     1.000     0.000     0.000     0.000     0.000
             0.000     1.000     0.000     0.000     0.000     0.000
       3         2        16        40
                 1        -6         2
             EfECC        BD   noSpInj
             0.000     0.000     1.000     0.000     0.000     0.000
             0.000     0.000     1.000     0.000     0.000     0.000
             0.000     0.000     1.000     0.000     0.000     0.000
       3        14        16        40
                 3         6         1
                LP      noBD     SpInj
             0.000     0.000     0.000     1.000     0.000     0.000
             0.000     0.000     0.000     1.000     0.000     0.000
             0.000     0.000     0.000     1.000     0.000     0.000
       3        14        16        40
                -3         6         2
             notLP      noBD   noSpInj
             0.000     0.000     0.000     0.000     1.000     0.000
             0.000     0.000     0.000     0.000     1.000     0.000
             0.000     0.000     0.000     0.000     1.000     0.000
       3        14        16        40
                 3         6         2
                LP      noBD   noSpInj
             0.000     0.000     0.000     0.000     0.000     1.000
             0.000     0.000     0.000     0.000     0.000     1.000
             0.000     0.000     0.000     0.000     0.000     1.000
          Otherwise
             1.000     0.000     0.000     0.000     0.000     0.000
             1.000     0.000     0.000     0.000     0.000     0.000
             1.000     0.000     0.000     0.000     0.000     0.000
42 Is a coolable debris bed formed after vessel breach?
       2       CDB     noCDB
       2         1         2
       6
       2        27        18
                 5         1
             MEjec      ECMR
             0.500     0.500
             0.100     0.900
             0.001     0.999
       2        27        34
                 5         1
             MEjec       ISp
             0.500     0.500
             0.100     0.900
             0.001     0.999
       3        14        27        41
                 2         4        -6
               ImP       PEj     Water
             0.900     0.100
             0.100     0.900
```

```
            0.001     0.999
       2       14        41
                1        -6
              HiP     Water
            0.999     0.001
            0.900     0.100
            0.500     0.500
       3       27        27        41
               -5        -4        -6
          noHEjec     NoPEj     Water
            0.999     0.001
            0.900     0.100
            0.500     0.500
        Otherwise
            0.000     1.000
            0.000     1.000
            0.000     1.000
43 Was power restored before or after 6 hrs.?
       2     L-AC     LL-AC
       2        1         2
       2
       1        1
                2
             EPAC
            0.100     0.900
            0.100     0.900
            0.100     0.900
        OTHERWISE
            1.000     0.000
            1.000     0.000
            1.000     0.000
44 Base pressure
       7     xxCC      xxST      xxLT      xxHC        Ex        xL        EL
       4        1         2         3         4         5         6         7
       7
       3       26        39        42
                2         2         2
           NoECHR    NoLCHR     NoCDB
            0.500     0.000     0.000     0.500     0.000     0.000     0.000
            0.500     0.000     0.000     0.500     0.000     0.000     0.000
            0.500     0.000     0.000     0.500     0.000     0.000     0.000
       1
       5     85.0      85.0     160.0      30.0      20.0      20.0      20.0
             85.0      85.0     160.0      40.0      30.0      30.0      20.0
             85.0      85.0     160.0      60.0      40.0      40.0      20.0
       4       26        39        40        42
                2         2         2         1
           NoECHR    NoLCHR    NoSpIn       CDB
            0.000     0.500     0.000     0.500     0.000     0.000     0.000
            0.000     0.500     0.000     0.500     0.000     0.000     0.000
            0.000     0.500     0.000     0.500     0.000     0.000     0.000
       1
       6     85.0      85.0     160.0      30.0      20.0      20.0      20.0
             85.0      85.0     160.0      40.0      30.0      30.0      20.0
             85.0      85.0     160.0      60.0      40.0      40.0      20.0
       4       26        39        40        42
                2         2         1         1
           NoECHR    NoLCHR      SpIn       CDB
            0.000     0.000     1.000     0.000     0.000     0.000     0.000
            0.000     0.000     1.000     0.000     0.000     0.000     0.000
```

```
             0.000     0.000     1.000     0.000     0.000     0.000     0.000
    1
    6         85.0      85.0     160.0      40.0      20.0      20.0      20.0
              85.0      85.0     160.0      40.0      30.0      30.0      20.0
              85.0      85.0     160.0      60.0      40.0      40.0      20.0
    2           26        39
                 2         2
            NoECHR    NoLCHR
             0.000     0.000     0.000     1.000     0.000     0.000     0.000
             0.000     0.000     0.000     1.000     0.000     0.000     0.000
             0.000     0.000     0.000     1.000     0.000     0.000     0.000
    1
    6         85.0      85.0     160.0      40.0      20.0      20.0      20.0
              85.0      85.0     160.0      40.0      30.0      30.0      20.0
              85.0      85.0     160.0      60.0      40.0      40.0      20.0
    2           26        39
                 1         2
              ECHR    NoLCHR
             0.000     0.000     0.000     0.000     1.000     0.000     0.000
             0.000     0.000     0.000     0.000     1.000     0.000     0.000
             0.000     0.000     0.000     0.000     1.000     0.000     0.000
    1
    6         85.0      85.0     160.0      40.0      20.0      20.0      20.0
              85.0      85.0     160.0      40.0      30.0      30.0      20.0
              85.0      85.0     160.0      60.0      40.0      40.0      20.0
    2           26        39
                 2         1
            NoECHR      LCHR
             0.000     0.000     0.000     0.000     0.000     1.000     0.000
             0.000     0.000     0.000     0.000     0.000     1.000     0.000
             0.000     0.000     0.000     0.000     0.000     1.000     0.000
    1
    6         85.0      85.0     160.0      40.0      20.0      20.0      20.0
              85.0      85.0     160.0      40.0      30.0      30.0      20.0
              85.0      85.0     160.0      60.0      40.0      40.0      20.0
               E&L
             0.000     0.000     0.000     0.000     0.000     0.000     1.000
             0.000     0.000     0.000     0.000     0.000     0.000     1.000
             0.000     0.000     0.000     0.000     0.000     0.000     1.000
    1
    6         85.0      85.0     160.0      40.0      20.0      20.0      20.0
              85.0      85.0     160.0      40.0      30.0      30.0      20.0
              85.0      85.0     160.0      60.0      40.0      40.0      20.0
45 Has a large leak (level 3 or 2) developed?
    2         Hole    noHole
    2            1         2
    2
    6            1         3        15        19        22        31
                -1        -2        -1         3         3         5
             noEH3     noEH2     noEB2      noEP      noEH     noICF
             0.000     1.000
             0.000     1.000
             0.000     1.000
          Otherwise
             1.000     0.000
             1.000     0.000
             1.000     0.000
46 Does a late hydrogen burn occur?
    2          LHB     noLHB
    2            1         2
```

```
          3
          5         21        29        39        45        44
                     2         2         2         2         4
                 NoEHB  NoHB@VB   NoLCHR    NoHole     HiCon
                 1.000    0.000
                 1.000    0.000
                 1.000    0.000
          4         21        29        45        39
                     2         2         2         1
                 NoEHB  NoHB@VB   NoHole      LCHR
                 1.000    0.000
                 1.000    0.000
                 1.000    0.000
              Otherwise
                 0.000    1.000
                 0.000    1.000
                 0.000    1.000
   47 H2 Burn Pressure
        1        FH2
        4        1.0
        7
        3         42        46        43
                   2         1         2
               NoCDS       LHB      LLAC
               1.000
               1.000
               1.000
       1
       7        55.0
                70.0
               110.0
       3          42        46        43
                   2         1         1
               NoCDS       LHB       LAC
               1.000
               1.000
               1.000
       1
       7        40.0
                55.0
                90.0
       3          28        46        43
                   1         1         2
                  DH       LHB      LLAC
               1.000
               1.000
               1.000
      1
      7         55.0
                70.0
               110.0
      3           28        46        43
                   1         1         1
                  DH       LHB       LAC
               1.000
               1.000
               1.000
      1
      7         40.0
                55.0
```

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```
          90.0
    4       28      42      46      43
             2       1       1       2
          NoDH     CDS     LMB    LLAC
         1.000
         1.000
         1.000
    1
    7     55.0
          70.0
          70.0
    4       28      42      46      43
             2       1       1       1
          NoDH     CDS     LMB     LAC
         1.000
         1.000
         1.000
    1
    7     40.0
          55.0
          70.0
       Otherwise
         1.000
         1.000
         1.000
    1
    7      0.0
           0.0
           0.0
48 Would containment fail due to HB and/or overpressure?
    2      LCF   NoLCF
    5        1       2
    2        6       7
        LFbase  PH2max
         'AND'
       'NORMAL'      3   134.0     2.5
                         134.0      15
                         100.0      15
                   CFP    MEAN   SIGMA
49 What is the mode of late containment failure?
    4      LF3     LF2      LH     NCF
    2        1       2       3       4
    3
    3       46      48      45
             1       1       2
           LMB     LCF  NoHole
         0.000   0.000   1.000   0.000
         0.000   0.000   1.000   0.000
         0.000   0.000   1.000   0.000
    3       46      48      45
             2       1       2
         NoLMB     LCF  NoHole
         0.100   0.900   0.000   0.000
         0.999   0.001   0.000   0.000
         1.000   0.000   0.000   0.000
       Otherwise
         0.000   0.000   0.000   1.000
         0.000   0.000   0.000   1.000
         0.000   0.000   0.000   1.000
50 Degree of late secondary containment bypass?
```

```
      3      LSB3      LSB2      LSB1
      2         1         2         3
      6
      1        32
                1
             LSB3
            1.000     0.000     0.000
            1.000     0.000     0.000
            1.000     0.000     0.000
      2        32        49
               -1         1
           noLSB3       LF3
            0.900     0.100     0.000
            0.999     0.001     0.000
            1.000     0.000     0.000
      1        49
                3
               LH
            1.000     0.000     0.000
            1.000     0.000     0.000
            1.000     0.000     0.000
      3        32        49        49
                2        -1        -3
             LSB2     noLF3      noLH
            0.000     1.000     0.000
            0.000     1.000     0.000
            0.000     1.000     0.000
      3        32        49        49
                3         2        -3
             LSB1       LF2      noLH
            0.000     0.100     0.900
            0.000     0.500     0.500
            0.000     0.900     0.100
        Otherwise
            0.000     0.000     1.000
            0.000     0.000     1.000
            0.000     0.000     1.000
  51 Fan coolers on after hydrogen burn?
      2      LLFC    noLLFC
      2         1         2
      3
      2        37        46
                1         1
              LFC       LHB
            0.000     1.000
            0.000     1.000
            0.000     1.000
      2        37        46
                1         2
              LFC     noLHB
            0.000     1.000
            0.000     1.000
            0.000     1.000
        Otherwise
            0.000     1.000
            0.000     1.000
            0.000     1.000
  52 Sprays on after hydrogen burn?
      2      LLSp    noLLSp
      2         1         2
```

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```
     4
     3      38      49      49
             1      -2      -5
           LSp  NoLP2   NoNCF
         0.900   0.100
         0.900   0.100
         0.500   0.500
     3      38      46      49
             1       1      -5
           LSp     LHB   NoNCF
         0.999   0.001
         0.900   0.100
         0.500   0.500
     2      38      46
             1       2
           LSp   noLHB
         0.999   0.001
         0.900   0.100
         0.500   0.500
       Otherwise
         0.000   1.000
         0.000   1.000
         0.000   1.000
53 Containment heat removal systems operating very late?
     2   LLCHR noLLCHR
     2       1       2
     2
     2      51      52
             2       2
        noLLFC  noLLSp
         0.000   1.000
         0.000   1.000
         0.000   1.000
       Otherwise
         1.000   0.000
         1.000   0.000
         1.000   0.000
54 Is there a vaporization release?
     2     Vap   noVap
     2       1       2
     2
     4      17      25      34      42
            -1      -1      -1       2
         NoESp   NoESp   NoIsp   NoCDB
         1.000   0.000
         1.000   0.000
         1.000   0.000
       Otherwise
         0.000   1.000
         0.000   1.000
         0.000   1.000
55 Degree of very late temperature induced leakage?
     3    LLT2    LLT1   noLLT
     2       1       2       3
     2
     6      41      41      41      53      45      48
            -1      -2      -4       2       2       2
       noR+A+P   noR+A     noR noLLCHR  noHole   NoLCF
         0.000   0.000   1.000
         0.000   0.000   1.000
```

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      0.000    0.000    1.000
    Otherwise
      0.000    0.000    1.000
      0.000    0.000    1.000
      0.000    0.000    1.000
56 Melt thru before OF?
    2        MT     NoMT
    2         1        2
    4
    5        42       45        48        55        54
              2        2         2         3         2
      NoCDB   noHole    NoLCF     NoLLT     NoVap
      0.100    0.900
      0.100    0.900
      0.001    0.999
    5        42       45        48        55        39
              2        2         2         3         1
      NoCDB   noHole    NoLCF     NoLLT       LSp
      0.100    0.900
      0.100    0.900
      0.001    0.999
    6        45       48        55        26        39        53
              2        2         3         2         2         2
     noHole    NoLCF    NoLLT    NoECHR    NoLCHR  noLLCHR
      0.500    0.500
      0.500    0.500
      0.100    0.900
    Otherwise
      0.000    1.000
      0.000    1.000
      0.000    1.000
57 Rapid depressurization given melt thru?
    2        DP     NoDP
    2         1        2
    5
    4        26       39        53        56
              2        2         2         1
     NoECHR   NoLCHR  NoLLCHR         MT
      0.900    0.100
      0.500    0.500
      0.100    0.900
    2        26       56
              1        1
       ECHR       MT
      0.900    0.100
      0.100    0.900
      0.001    0.999
    2        39       56
              1        1
       LCHR       MT
      0.900    0.100
      0.100    0.900
      0.001    0.999
    2        53       56
              1        1
      LLCHR       MT
      0.900    0.100
      0.100    0.900
      0.001    0.999
    otherwise
```

```
         0.000   1.000
         0.000   1.000
         0.000   1.000
 58 Final cont. failure mode
     4    LLP3    LLP2      MT  NoLLCF
     2       1       2       3       4
     8
     5      53      45      48      55      42
             1       2       2       3       2
         LLCHR  NoHole   NoLCF   NoLLT   NoCDB
         0.000   0.000   0.100   0.900
         0.000   0.000   0.500   0.500
         0.000   0.000   0.900   0.100
     5      53      45      48      55      56
             2       2       2       3       2
       NoLLCHR  NoHole   NoLCF   NoLLT    NoMT
         0.100   0.800   0.000   0.100
         0.900   0.100   0.400   0.000
         1.000   0.000   0.400   0.000
     6      45      48      55      56      57      53
             2       2       3       1       1       2
        NoHole   NoLCF   NoLLT      MT      DP NoLLCHR
         0.000   0.000   1.000   0.000
         0.000   0.000   1.000   0.000
         0.000   0.000   1.000   0.000
     6      45      48      55      56      57      53
             2       2       3       1       2       2
        NoHole   NoLCF   NoLLT      MT    NoDP NoLLCHR
         0.100   0.800   0.100   0.000
         0.900   0.100   0.000   0.000
         1.000   0.000   0.000   0.000
       otherwise
         0.000   0.000   0.000   1.000
         0.000   0.000   0.000   1.000
         0.000   0.000   0.000   1.000
 59 Degree of auxiliary building bypass very late?
     3    LLB3    LLB2     LB1
     2       1       2       3
     6
     1      50
             1
          LSB3
         1.000   0.000   0.000
         1.000   0.000   0.000
         1.000   0.000   0.000
     2      50      57
            -1       1
        noLSB2    LLP3
         0.900   0.100   0.000
         0.999   0.001   0.000
         1.000   0.000   0.000
     2      50      57
             2      -1
          LSB2  noLLP3
         0.000   1.000   0.000
         0.000   1.000   0.000
         0.000   1.000   0.000
     2      50      57
             3       2
          LSB1    LLP2
          0.000   0.100   0.900
          0.000   0.500   0.500
          0.000   0.900   0.100
   3         58      57      55
              2      -1       1
           LSB1  NoLLF3    LLF2
          0.000   0.100   0.900
          0.000   0.500   0.500
          0.000   0.900   0.100
        Otherwise
          0.000   0.000   1.000
          0.000   0.000   1.000
          0.000   0.000   1.000
'SURRY TYPE WITH EH'
'OPTIMISTIC'  'CENTRAL'  'PESSIMISTIC'
  1         'CFBINS'
 15      14 'BIN15a' 'BIN14a' 'BIN13a' 'BIN10' 'BIN9' 'BIN8' 'BIN7' 'BIN6'
            'BIN5' 'BIN4' 'BIN3' 'BIN2a' 'BIN2' 'BIN1a' 'BIN1'
  6       1     22    31     49     58     3     3           BIN15a
                 2     5      4      4    -1    -2
              NoEH NoICF NoLCF NoLLCFNoEE3NoEE2
  2       2     58    53                               BIN14a
                 3     1
             LLMT LLCHR
  2       3     58    53                               BIN13a
                 3     2
             LLMT NoLLCHR
  1       4     49                                     BIN10
                 2
               LF2
  1       4     58
                 2
              LLF2
  3       5     49     49     38                       BIN9
                -2     -4     -1
            NoLF2     LCF NoLSp
  4       5     49     49     42     52
                -2     -4      2     -1
            NoLF2     LCF NoCDB NoLLSp
  3       5     58     52     42
                 1     -1      2
               LF3 NoLLSpNoCDB
  4       6     49     49     38     52                 BIN8
                -2     -4      1      1
            NoLF2     LCF    LSp   LLSp
  4       6     49     49     38     42
                -2     -4      1      1
            NoLF2     LCF    LSp    CDB
  2       6     58     52
                 1      1
              LLF3   LLSp
  2       6     58     42
                 1      1
              LLF3    CDB
  5       7      3     31     49     58     34           BIN7
                 2      5      4      4      1
               EE2 NoICF  NoLCF NoLLCF   LSp
  5       7      3     31     49     58     38
                 2      5      4      4      1
               EE2 NoICF  NoLCF NoLLCF   LSp
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5     7     3    31    49    56    52
            2     5     4     4     1
          KE2 NoICP NoLCP NoLLCP LLSp
7     8     3    31    49    58    34    38    52  BIN6
            2     3     4     4    -1    -1    -1
          KE2 NoICP NoLCP NoLLCPNoISp NoLSp NoLLSp
2     9    14    22                      BIN 5
            3     1
          LoP    HH
3    10    14    31    34                BIN4
           -1    -5     1
         NoHP   ICP   ISp
4    10    14    31    42    39
           -1    -5     1     1
         NoHP   ICP   CDB  LCHR
4    10    14    31    42    53
           -1    -5     1     1
         NoHP   ICP   CDB LLCHR
4    11    14    31    34    42          BIN3
           -1    -5    -1     2
         NoHP   ICP NoISp NoCDB
5    11    14    31    34    39    53
           -1    -5    -1    -1    -1
         NoHP   ICP NoISp NoLCHRNoLLCHR
4    12    14    28    31    34             BIN2a
            1     1    -5     1
           HP    DH   ICP   ISp
5    12    14    28    31    42    39
            1     1    -5     1     1
           HP    DH   ICP   CDB  LCHR
5    12    14    28    31    42    53
            1     1    -5     1     1
           HP    DH   ICP   CDB LLCHR
4    13    14    28    31    34                     BIN2
            1     2    -5     1
          HiP  NoDH   ICP   ISp
5    13    14    28    31    42    39
            1     2    -5     1     1
          HiP  NoDH   ICP   CDB  LCHR
5    13    14    28    31    42    53
            1     2    -5     1     1
          HiP  NoDH   ICP   CDB LLCHR
5    14    14    28    31    34    42                          BIN1a
            1     1    -5    -1     2
           HP    DH   ICP NoISp NoCDB
5    14    14    28    31    34    53
            1     1    -5    -1    -1
           HP    DH   ICP NoISp NoLLCHR
5    14    14    28    31    34    39
            1     1    -5    -1    -1
           HP    DH   ICP NoISp NoLCHR
5    15    14    28    31    34    42      BIN1
            1     2    -5    -1     2
          HiP  NoDH   ICP NoISp NoCDB
5    15    14    28    31    34    53
            1     2    -5    -1    -1
          HiP  NoDH   ICP NoISp NoLLCHR
5    15    14    28    31    34    39
            1     2    -5    -1    -1
          HiP  NoDH   ICP NoISp NoLCHR
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Appendix D

DETAILED CONTAINMENT EVENT TREE OUTPUT FOR THREE REPRESENTATIVE DAMAGE STATES

The actual containment event tree output for three damage states, AYYB, TNNN, and TYYB, are presented in this appendix. These results reflect an additional level of detail relative to the summary of results provided in the main report and Appendix B. The output is sorted by containment failure mode, the operability of containment sprays, and the coolability of the debris bed. The frequency of each combination of these key parameters is provided. The results for the optimistic and pessimistic cases are provided in addition to the central estimate.

THIS FILE CONTAINS THE OUTPUT OF THE CONTAINMENT EVENT ANALYSIS FOR THE SURRY PLANT; DAMAGE STATES AYYB, TNNN, AND TYYN. DUE TO THE VOLUME OF THE OUTPUT, THE DETAILS OF THE OTHER DAMAGE STATES ARE NOT PROVIDED. ALL OF THE RESULTS INCLUDE THE ASSESSMENT OF DIRECT HEATING AS DISCUSSED IN THE MAIN REPORT. THE RESULTS ARE SORTED BY CONTAINMENT FAILURE MODES, THE PRESSURE OF THE REACTOR COOLANT SYSTEM AT THE TIME OF CORE MELT, THE OPERABILITY OF THE SPRAYS AT THREE TIME INTERVALS IN THE SEQUENCE (EARLY, INTERMEDIATE, AND LATE, AS DEFINED IN THE CONTAINMENT EVENT TREE INPUT, AND BY THE STATUS OF THE DEBRIS BED (COOLABLE OR NON-COOLABLE).

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SURRY AYYB WITH DH


THESE RESULTS ARE FOR THE  OPTIMISTIC       WALKTHROUGH


 FREQUENCY  CFM        RCSPress  ESpr      I Spr     L Spr     CDB
 4.4864E-01 NCF        LoP       Yes       Yes       Yes       Short
 4.0377E-01 NCF        LoP       Yes       Yes       Yes       No
 5.9091E-03 EE1        LoP       Yes       Yes       Yes       Short
 5.3182E-03 EE1        LoP       Yes       Yes       Yes       No
 4.9500E-02 LLM        LoP       Yes       Yes       Yes       No
 3.9960E-02 LP2        LoP       Yes       Yes       Yes       Short
 3.6364E-02 LP2        LoP       Yes       Yes       Yes       No
 3.9990E-04 LP2        LoP       Yes       Part      No        Short
 3.6382E-04 LP2        LoP       Yes       Part      No        No
 4.9950E-03 LP3        LoP       Yes       Yes       Yes       Short
 4.5453E-03 LP3        LoP       Yes       Yes       Yes       No

.9997630     TOTAL FREQUENCY OF BINS PRINTED


TOTAL PROBABILITY IN ALL BINS = .9999999
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 1.9804E-06
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000002
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SURRY AYYB WITH DH

THESE ARE THE SORT  1 RESULTS FOR THE   OPTIMISTIC       WALKTHROUGH

  CFM          ESpr         I Spr        L Spr        CDB          RCSPress
  NCP          Yes          Yes          Yes          Short        LoP
                                                     4.4864E-01   4.4864E-01
  NCP          Yes          Yes          Yes          No           LoP
 8.5241E-01   8.5241E-01   8.5241E-01   8.5241E-01   4.0377E-01   4.0377E-01
  EE1          Yes          Yes          Yes          Short        LoP
                                                     5.9091E-03   5.9091E-03
  EE1          Yes          Yes          Yes          No           LoP
 1.1227E-02   1.1227E-02   1.1227E-02   1.1227E-02   5.3182E-03   5.3182E-03
  LLM          Yes          Yes          Yes          No           LoP
 4.9500E-02   4.9500E-02   4.9500E-02   4.9500E-02   4.9500E-02   4.9500E-02
  LP2          Yes          Yes          Yes          Short        LoP
                                                     3.9960E-02   3.9960E-02
  LP2          Yes          Yes          Yes          No           LoP
                           7.6324E-02   7.6324E-02   3.6364E-02   3.6364E-02
  LP2          Yes          Part         No           Short        LoP
                                                     3.9990E-04   3.9990E-04
  LP2          Yes          Part         No           No           LoP
 7.7087E-02   7.7087E-02   7.6372E-04   7.6372E-04   3.6382E-04   3.6382E-04
  LP3          Yes          Yes          Yes          Short        LoP
                                                     4.9950E-03   4.9950E-03
  LP3          Yes          Yes          Yes          No           LoP
 9.5403E-03   9.5403E-03   9.5403E-03   9.5403E-03   4.5453E-03   4.5453E-03
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SURRY AYYB WITH DH

THESE RESULTS ARE FOR THE  CENTRAL         WALKTHROUGH

FREQUENCY  CFM        RCSPress  ESpr      I Spr     L Spr     CDB
2.1054E-01 NCF        LoP       Yes       Yes       Yes       Short
2.8750E-01 NCF        LoP       Yes       Yes       Yes       No
6.0774E-03 EE1        LoP       Yes       Yes       Yes       Short
8.2983E-03 EE1        LoP       Yes       Yes       Yes       No
2.9646E-01 LLM        LoP       Yes       Yes       Yes       No
7.3311E-04 LLM        LoP       Yes       Part      No        No
4.8224E-04 EE2        LoP       Yes       Yes       Yes       Short
1.3171E-03 EE2        LoP       Yes       Yes       Yes       No
1.4596E-04 EE2        LoP       Yes       Part      No        No
2.4065E-03 LP2        LoP       Yes       Yes       Yes       Short
6.5063E-03 LP2        LoP       Yes       Yes       Yes       No
2.6741E-03 LP2        LoP       Yes       Part      No        Short
7.2359E-03 LP2        LoP       Yes       Part      No        No
2.1662E-02 LP3        LoP       Yes       Yes       Yes       Short
5.8568E-02 LP3        LoP       Yes       Yes       Yes       No
2.4094E-02 LP3        LoP       Yes       Part      No        Short
6.5138E-02 LP3        LoP       Yes       Part      No        No

.9998323     TOTAL FREQUENCY OF BINS PRINTED

TOTAL PROBABILITY IN ALL BINS = 1.000000
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 1.1481E-05
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000011
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 SURRY AYYB WITH DH

THESE ARE THE SORT  1 RESULTS FOR THE   CENTRAL          WALKTHROUGH

  CFM          ESpr         I Spr        L Spr        CDB          RCSPress
  NCP          Yes          Yes          Yes          Short        LoP
                                                     2.1054E-01   2.1054E-01
  NCP          Yes          Yes          Yes          No           LoP
 4.9804E-01   4.9804E-01   4.9804E-01   4.9804E-01   2.8750E-01   2.8750E-01
  EE1          Yes          Yes          Yes          Short        LoP
                                                     6.0774E-03   6.0774E-03
  EE1          Yes          Yes          Yes          No           LoP
 1.4376E-02   1.4376E-02   1.4376E-02   1.4376E-02   8.2983E-03   8.2983E-03
  LLM          Yes          Yes          Yes          No           LoP
                           2.9646E-01   2.9646E-01   2.9646E-01   2.9646E-01
  LLM          Yes          Part         No           No           LoP
 2.9719E-01   2.9719E-01   7.3311E-04   7.3311E-04   7.3311E-04   7.3311E-04
  EE2          Yes          Yes          Yes          Short        LoP
                                                     4.8224E-04   4.8224E-04
  EE2          Yes          Yes          Yes          No           LoP
                           1.7993E-03   1.7993E-03   1.3171E-03   1.3171E-03
  EE2          Yes          Part         No           No           LoP
 1.9453E-03   1.9453E-03   1.4596E-04   1.4596E-04   1.4596E-04   1.4596E-04
  LP2          Yes          Yes          Yes          Short        LoP
                                                     2.4065E-03   2.4065E-03
  LP2          Yes          Yes          Yes          No           LoP
                           8.9128E-03   8.9128E-03   6.5063E-03   6.5063E-03
  LP2          Yes          Part         No           Short        LoP
                                                     2.6741E-03   2.6741E-03
  LP2          Yes          Part         No           No           LoP
 1.8823E-02   1.8823E-02   9.9100E-03   9.9100E-03   7.2359E-03   7.2359E-03
  LP3          Yes          Yes          Yes          Short        LoP
                                                     2.1662E-02   2.1662E-02
  LP3          Yes          Yes          Yes          No           LoP
                           8.0229E-02   8.0229E-02   5.8568E-02   5.8568E-02
  LP3          Yes          Part         No           Short        LoP
                                                     2.4094E-02   2.4094E-02
  LP3          Yes          Part         No           No           LoP
 1.6946E-01   1.6946E-01   8.9232E-02   8.9232E-02   6.5138E-02   6.5138E-02
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SURRY AYYB WITH DH

THESE RESULTS ARE FOR THE  PESSIMISTIC      WALKTHROUGH

FREQUENCY  CFM        RCSPress  ESpr      I Spr     L Spr     CDB
1.3327E-02 NCF        LoP       Yes       Yes       Yes       Short
3.9113E-03 NCF        LoP       Yes       Yes       Yes       No
7.1738E-04 EE1        LoP       Yes       Yes       Yes       Short
2.1046E-04 EE1        LoP       Yes       Yes       Yes       No
3.7102E-02 LLM        LoP       Yes       Yes       Yes       No
1.3600E-04 EE2        LoP       Yes       Yes       Yes       Short
4.7567E-04 EE2        LoP       Yes       Yes       Yes       No
1.3600E-04 EE2        LoP       Yes       Part      No        Short
4.7567E-04 EE2        LoP       Yes       Part      No        No
1.4044E-02 LP3        LoP       Yes       Yes       Yes       Short
4.1224E-02 LP3        LoP       Yes       Yes       Yes       No
3.0381E-02 LP3        LoP       Yes       Part      No        Short
1.0599E-01 LP3        LoP       Yes       Part      No        No
2.2729E-03 LM         LoP       Yes       Yes       Yes       Short
2.3479E-02 LM         LoP       Yes       Yes       Yes       No
6.9510E-02 IHS        LoP       Yes       Yes       Yes       Short
2.4251E-01 IHS        LoP       Yes       Yes       Yes       No
6.9510E-02 IHS        LoP       Yes       Part      No        Short
2.4251E-01 IHS        LoP       Yes       Part      No        No
4.9886E-02 IA         LoP       Yes       No        No        Short
4.9886E-02 IA         LoP       Yes       No        No        No
4.3217E-04 EH         LoP       Yes       Part      No        Short
1.5081E-03 EH         LoP       Yes       Part      No        No
1.1345E-04 EH         LoP       Yes       No        No        Short
1.1371E-04 EH         LoP       Yes       No        No        No

.9998615     TOTAL FREQUENCY OF BINS PRINTED

TOTAL PROBABILITY IN ALL BINS = .9999899
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 1.1378E-05
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000011
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SURRY AYYB WITH DH

THESE ARE THE SORT  1 RESULTS FOR THE   PESSIMISTIC      WALKTHROUGH

  CFM          ESpr         I Spr        L Spr        CDB          RCSPress
  NCF          Yes          Yes          Yes          Short        LoP
                                                      1.3327E-02   1.3327E-02
  NCF          Yes          Yes          Yes          No           LoP
1.7238E-02   1.7238E-02   1.7238E-02   1.7238E-02   3.9113E-03   3.9113E-03
  EE1          Yes          Yes          Yes          Short        LoP
                                                      7.1738E-04   7.1738E-04
  EE1          Yes          Yes          Yes          No           LoP
9.2764E-04   9.2764E-04   9.2784E-04   9.2784E-04   2.1046E-04   2.1046E-04
  LLM          Yes          Yes          Yes          No           LoP
3.7102E-02   3.7102E-02   3.7102E-02   3.7102E-02   3.7102E-02   3.7102E-02
  EE2          Yes          Yes          Yes          Short        LoP
                                                      1.3600E-04   1.3600E-04
  EE2          Yes          Yes          Yes          No           LoP
                          6.1167E-04   6.1167E-04   4.7567E-04   4.7567E-04
  EE2          Yes          Part         No           Short        LoP
                                                      1.3600E-04   1.3600E-04
  EE2          Yes          Part         No           No           LoP
1.2233E-03   1.2233E-03   6.1167E-04   6.1167E-04   4.7567E-04   4.7567E-04
  LP3          Yes          Yes          Yes          Short        LoP
                                                      1.4044E-02   1.4044E-02
  LP3          Yes          Yes          Yes          No           LoP
                          5.5269E-02   5.5269E-02   4.1224E-02   4.1224E-02
  LP3          Yes          Part         No           Short        LoP
                                                      3.0381E-02   3.0381E-02
  LP3          Yes          Part         No           No           LoP
1.9164E-01   1.9164E-01   1.3638E-01   1.3638E-01   1.0599E-01   1.0599E-01
  LH           Yes          Yes          Yes          Short        LoP
                                                      2.2729E-03   2.2729E-03
  LH           Yes          Yes          Yes          No           LoP
2.5752E-02   2.5752E-02   2.5752E-02   2.5752E-02   2.3479E-02   2.3479E-02
  IHS          Yes          Yes          Yes          Short        LoP
                                                      6.9510E-02   6.9510E-02
  IHS          Yes          Yes          Yes          No           LoP
                          3.1202E-01   3.1202E-01   2.4251E-01   2.4251E-01
  IHS          Yes          Part         No           Short        LoP
                                                      6.9510E-02   6.9510E-02
  IHS          Yes          Part         No           No           LoP
6.2403E-01   6.2403E-01   3.1202E-01   3.1202E-01   2.4251E-01   2.4251E-01
  IA           Yes          No           No           Short        LoP
                                                      4.9886E-02   4.9886E-02
  IA           Yes          No           No           No           LoP
9.9772E-02   9.9772E-02   9.9772E-02   9.9772E-02   4.9886E-02   4.9886E-02
  EH           Yes          Part         No           Short        LoP
                                                      4.3217E-04   4.3217E-04
  EH           Yes          Part         No           No           LoP
                          1.9403E-03   1.9403E-03   1.5081E-03   1.5081E-03
  EH           Yes          No           No           Short        LoP
                                                      1.1345E-04   1.1345E-04
  EH           Yes          No           No           No           LoP
2.1669E-03   2.1669E-03   2.2666E-04   2.2666E-04   1.1321E-04   1.1321E-04
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 SURRY TMNN WITH DB

THESE RESULTS ARE FOR THE  OPTIMISTIC       WALKTHROUGH

 FREQUENCY   CFM        RCSPress  ESpr       I Spr      L Spr      CDB
 7.2679E-01 NCP         ImP       No         No         Yes        Long
 7.2679E-02 NCP         ImP       No         No         Yes        No
 8.0754E-02 NCP         LoP       No         No         Yes        No
 9.5727E-03 EE1         ImP       No         No         Yes        Long
 9.5691E-04 EE1         ImP       No         No         Yes        No
 1.0634E-03 EE1         LoP       No         No         Yes        No
 8.9093E-03 LLM         ImP       No         No         Yes        No
 3.6832E-04 LLM         ImP       No         No         No         Short
 9.8993E-03 LLM         LoP       No         No         Yes        No
 6.4735E-02 LP2         ImP       No         No         Yes        Long
 6.5452E-03 LP2         ImP       No         No         Yes        No
 3.5621E-04 LP2         ImP       No         No         No         Short
 7.2724E-03 LP2         LoP       No         No         Yes        No
 8.0919E-03 LP3         ImP       No         No         Yes        Long
 8.1788E-04 LP3         ImP       No         No         Yes        No
 9.0886E-04 LP3         LoP       No         No         Yes        No

.9997211     TOTAL FREQUENCY OF BINS PRINTED

TOTAL PROBABILITY IN ALL BINS = 1.000000
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 5.7652E-06
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000006
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 SURRY TMLB WITH DH

THESE ARE THE SORT  1 RESULTS FOR THE   OPTIMISTIC       WALKTHROUGH

  CFM          RSpr         I Spr        L Spr        CDB          RCSPress
  NCF          No           No           Yes          Long         ImP
                                                     7.2679E-01  7.2679E-01
  NCF          No           No           Yes          No           ImP
                                                                  7.2679E-02
  NCF          No           No           Yes          No           LoP
 8.8022E-01   8.8022E-01   8.8022E-01   8.8022E-01   1.5343E-01  8.0754E-02
  EE1          No           No           Yes          Long         ImP
                                                     9.5727E-03  9.5727E-03
  EE1          No           No           Yes          No           ImP
                                                                  9.5691E-04
  EE1          No           No           Yes          No           LoP
 1.1593E-02   1.1593E-02   1.1593E-02   1.1593E-02   2.0204E-03  1.0634E-03
  LLN          No           No           Yes          No           ImP
                                                                  8.9090E-03
  LLN          No           No           Yes          No           LoP
                                        1.8808E-02   1.8808E-02  9.8993E-03
  LLN          No           No           No           Short        ImP
 1.9177E-02   1.9177E-02   1.9177E-02   3.6832E-04   3.6832E-04  3.6832E-04
  LP2          No           No           Yes          Long         ImP
                                                     6.4735E-02  6.4735E-02
  LP2          No           No           Yes          No           ImP
                                                                  6.5452E-03
  LP2          No           No           Yes          No           LoP
                                        7.8553E-02   1.3818E-02  7.2724E-03
  LP2          No           No           No           Short        ImP
 7.8909E-02   7.8909E-02   7.8909E-02   3.3621E-04   3.5621E-04  3.5621E-04
  LP3          No           No           Yes          Long         ImP
                                                     8.0919E-03  8.0919E-03
  LP3          No           No           Yes          No           ImP
                                                                  8.1788E-04
  LP3          No           No           Yes          No           LoP
 9.8186E-03   9.8186E-03   9.8186E-03   9.8186E-03   1.7267E-03  9.0886E-04
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SURRY [illegible] WITH DH

THESE RESULTS ARE FOR THE CENTRAL WALKTHROUGH

FREQUENCY	CFM	RCSPress	ESpr	I Spr	L Spr	CDB
2.7306E-01	NCP	HiP	No	No	Yes	Long
7.3315E-02	NCP	HiP	No	No	Yes	Short
1.9243E-02	NCP	HiP	No	No	Yes	No
1.5613E-02	NCP	ImP	No	No	Yes	Long
3.6878E-02	NCP	ImP	No	No	Yes	Short
7.1406E-02	NCP	ImP	No	No	Yes	No
3.6731E-02	NCP	LoP	No	No	Yes	Short
7.8797E-02	NCP	LoP	No	No	Yes	No
7.8823E-03	EE1	HiP	No	No	Yes	Long
2.1163E-03	EE1	HiP	No	No	Yes	Short
5.5542E-04	EE1	HiP	No	No	Yes	No
4.4489E-04	EE1	ImP	No	No	Yes	Long
1.0645E-03	EE1	ImP	No	No	Yes	Short
2.0607E-03	EE1	ImP	No	No	Yes	No
1.0603E-03	EE1	LoP	No	No	Yes	Short
2.2744E-03	EE1	LoP	No	No	Yes	No
1.9842E-02	LLM	HiP	No	No	Yes	No
1.0837E-02	LLM	HiP	No	No	No	Short
1.2039E-03	LLM	HiP	No	No	No	No
7.3629E-02	LLM	ImP	No	No	Yes	No
1.6353E-03	LLM	ImP	No	No	No	Short
4.4678E-03	LLM	ImP	No	No	No	No
8.1252E-02	LLM	LoP	No	No	Yes	No
1.1491E-03	LLM	LoP	No	No	No	Short
4.9304E-03	LLM	LoP	No	No	No	No
6.3846E-04	EE2	HiP	No	No	Yes	Long
1.6976E-04	EE2	HiP	No	No	Yes	Short
3.3034E-04	EE2	ImP	No	No	Yes	No
3.6464E-04	EE2	LoP	No	No	Yes	No
3.1216E-03	LP2	HiP	No	No	Yes	Long
8.3813E-04	LP2	HiP	No	No	Yes	Short
4.3506E-04	LP2	HiP	No	No	Yes	No
3.2510E-03	LP2	HiP	No	No	No	Short
3.6050E-04	LP2	HiP	No	No	No	No
1.7606E-04	LP2	ImP	No	No	Yes	Long
4.2154E-04	LP2	ImP	No	No	Yes	Short
1.6159E-03	LP2	ImP	No	No	Yes	No
4.8946E-04	LP2	ImP	No	No	No	Short
1.3394E-03	LP2	ImP	No	No	No	No
4.1991E-04	LP2	LoP	No	No	Yes	Short
1.7833E-03	LP2	LoP	No	No	Yes	No
3.4437E-04	LP2	LoP	No	No	No	Short
1.4786E-03	LP2	LoP	No	No	No	No
2.8095E-02	LP3	HiP	No	No	Yes	Long
7.5432E-03	LP3	HiP	No	No	Yes	Short
3.9199E-03	LP3	HiP	No	No	Yes	No
2.9273E-02	LP3	HiP	No	No	No	Short
3.2523E-03	LP3	HiP	No	No	No	No
1.5057E-03	LP3	ImP	No	No	Yes	Long
3.7942E-03	LP3	ImP	No	No	Yes	Short
1.4546E-02	LP3	ImP	No	No	Yes	No
4.4182E-03	LP3	ImP	No	No	No	Short
1.2068E-02	LP3	ImP	No	No	No	No

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3.7791E-03 LP3        LoP       No        No        Yes       Short
1.6052E-02 LP3        LoP       No        No        Yes       No
3.1041E-03 LP3        LoP       No        No        No        Short
1.3318E-02 LP3        LoP       No        No        No        No
3.3400E-03 LH         HiP       No        No        Yes       Long
8.9699E-04 LH         HiP       No        No        Yes       Short
4.7074E-04 LH         HiP       No        No        Yes       No
1.1069E-03 LH         HiP       No        No        No        Short
1.2289E-04 LH         HiP       No        No        No        No
1.8830F-04 LH         ImP       No        No        Yes       Long
4.5108E-04 LH         ImP       No        No        Yes       Short
1.7471E-03 LH         ImP       No        No        Yes       No
1.6704E-04 LH         ImP       No        No        No        Short
4.5622E-04 LH         ImP       No        No        No        No
4.4934E-04 LH         LoP       No        No        Yes       Short
1.9201E-03 LH         LoP       No        No        Yes       No
1.1735E-04 LH         LoP       No        No        No        Short
5.0358E-04 LH         LoP       No        No        No        No
3.1273E-03 ID         HiP       No        No        Yes       Long
3.4715E-04 ID         HiP       No        No        Yes       No
3.4726E-04 ID         HiP       No        No        No        Short

.9993481      TOTAL FREQUENCY OF BINS PRINTED

TOTAL PROBABILITY IN ALL BINS = 1.000000
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 2.1421E-05
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000022
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AVAILABLE

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SURRY [illegible] WITH DE

THESE ARE THE SORT  1 RESULTS FOR THE   CENTRAL          WALKTHROUGH

 CFN          ESpr         I Spr        L Spr        CDB          RCSPress
 NCF          No           No           Yes          Long         HiP
                                                                  2.7306E-01
 NCF          No           No           Yes          Long         ImP
                                                     2.8848E-01   1.5413E-02
 NCF          No           No           Yes          Short        HiP
                                                                  7.3315E-02
 NCF          No           No           Yes          Short        ImP
                                                                  3.6878E-02
 NCF          No           No           Yes          Short        LoP
                                                     1.4693E-01   3.6731E-02
 NCF          No           No           Yes          No           HiP
                                                                  1.9243E-02
 NCF          No           No           Yes          No           ImP
                                                                  7.1406E-02
 NCF          No           No           Yes          No           LoP
6.0485E-01   6.0485E-01   6.0485E-01   6.0485E-01   1.6945E-01   7.8797E-02
 EE1          No           No           Yes          Long         HiP
                                                                  7.8823E-03
 EE1          No           No           Yes          Long         ImP
                                                     8.3272E-03   4.4489E-04
 EE1          No           No           Yes          Short        HiP
                                                                  2.1163E-03
 EE1          No           No           Yes          Short        ImP
                                                                  1.0645E-03
 EE1          No           No           Yes          Short        LoP
                                                     4.2411E-03   1.0603E-03
 EE1          No           No           Yes          No           HiP
                                                                  5.5542E-04
 EE1          No           No           Yes          No           ImP
                                                                  2.0607E-03
 EE1          No           No           Yes          No           LoP
1.7459E-02   1.7459E-02   1.7459E-02   1.7459E-02   4.8904E-03   2.2744E-03
 LLM          No           No           Yes          No           HiP
                                                                  1.9842E-02
 LLM          No           No           Yes          No           ImP
                                                                  7.3629E-02
 LLM          No           No           Yes          No           LoP
                                        1.7472E-01   1.7472E-01   8.1252E-02
 LLM          No           No           No           Short        HiP
                                                                  1.0837E-02
 LLM          No           No           No           Short        ImP
                                                                  1.6353E-03
 LLM          No           No           No           Short        LoP
                                                     1.3621E-02   1.1491E-03
 LLM          No           No           No           No           HiP
                                                                  1.2039E-03
 LLM          No           No           No           No           ImP
                                                                  4.4678E-03
 LLM          No           No           No           No           LoP
1.9895E-01   1.9895E-01   1.9895E-01   2.4223E-02   1.0602E-02   4.9304E-03
 EE2          No           No           Yes          Long         HiP
                                                     6.3846E-04   6.3846E-04
 EE2          No           No           Yes          Short        HiP
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                                                                  1.6976E-04    1.6976E-04
   HE2          No           No           Yes          No           ImP
                                                                                3.3034E-04
   HE2          No           No           Yes          No           LoP
1.5032E-03   1.5032E-03   1.5032E-03   1.5032E-03   6.9498E-04    3.6464E-04
   LP2          No           No           Yes          Long         HiP
                                                                                3.1216E-03
   LP2          No           No           Yes          Long         ImP
                                                                  3.2977E-03    1.7606E-04
   LP2          No           No           Yes          Short        HiP
                                                                                8.3810E-04
   LP2          No           No           Yes          Short        ImP
                                                                                4.2154E-04
   LP2          No           No           Yes          Short        LoP
                                                                  1.6796E-03    4.1991E-04
   LP2          No           No           Yes          No           HiP
                                                                                4.3506E-04
   LP2          No           No           Yes          No           ImP
                                                                                1.6159E-03
   LP2          No           No           Yes          No           LoP
                                                     8.8115E-03   3.8342E-03    1.7833E-03
   LP2          No           No           No           Short        HiP
                                                                                3.2510E-03
   LP2          No           No           No           Short        ImP
                                                                                4.8946E-04
   LP2          No           No           No           Short        LoP
                                                                  4.0848E-03    3.4437E-04
   LP2          No           No           No           No           HiP
                                                                                3.6050E-04
   LP2          No           No           No           No           ImP
                                                                                1.3394E-03
   LP2          No           No           No           No           LoP
1.6075E-02   1.6075E-02   1.6075E-02   7.2633E-03   3.1785E-03    1.4786E-03
   LP3          No           No           Yes          Long         HiP
                                                                                2.8095E-02
   LP3          No           No           Yes          Long         ImP
                                                                  2.9680E-02    1.5857E-03
   LP3          No           No           Yes          Short        HiP
                                                                                7.5432E-03
   LP3          No           No           Yes          Short        ImP
                                                                                3.7942E-03
   LP3          No           No           Yes          Short        LoP
                                                                  1.5117E-02    3.7791E-03
   LP3          No           No           Yes          No           HiP
                                                                                3.9199E-03
   LP3          No           No           Yes          No           ImP
                                                                                1.4546E-02
   LP3          No           No           Yes          No           LoP
                                                     7.9315E-02   3.4518E-02    1.6052E-02
   LP3          No           No           No           Short        HiP
                                                                                2.9273E-02
   LP3          No           No           No           Short        ImP
                                                                                4.4182E-03
   LP3          No           No           No           Short        LoP
                                                                  3.6795E-02    3.1041E-03
   LP3          No           No           No           No           HiP
                                                                                3.2523E-03
   LP3          No           No           No           No           ImP
                                                                                1.2068E-02
   LP3          No           No           No           No           LoP
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1.4475E-01  1.4475E-01  1.4475E-01  6.5433E-02  2.8638E-02  1.3318E-02
 LH          No          No          Yes         Long        HiP
                                                            3.3408E-03
 LH          No          No          Yes         Long        ImP
                                                3.5291E-03  1.8830E-04
 LH          No          No          Yes         Short       HiP
                                                            8.9699E-04
 LH          No          No          Yes         Short       ImP
                                                            4.5108E-04
 LH          No          No          Yes         Short       LoP
                                                1.7974E-03  4.4934E-04
 LH          No          No          Yes         No          HiP
                                                            4.7074E-04
 LH          No          No          Yes         No          ImP
                                                            1.7471E-03
 LH          No          No          Yes         No          LoP
                                    9.4724E-03  4.1459E-03  1.9281E-03
 LH          No          No          No          Short       HiP
                                                            1.1069E-03
 LH          No          No          No          Short       ImP
                                                            1.6704E-04
 LH          No          No          No          Short       LoP
                                                1.3912E-03  1.1735E-04
 LH          No          No          No          No          HiP
                                                            1.2289E-04
 LH          No          No          No          No          ImP
                                                            4.5622E-04
 LH          No          No          No          No          LoP
1.1946E-02  1.1946E-02  1.1946E-02  2.4739E-03  1.0827E-03  5.0358E-04
 ID          No          No          Yes         Long        HiP
                                                3.1273E-03  3.1273E-03
 ID          No          No          Yes         No          HiP
                                    3.4744E-03  3.4715E-04  3.4715E-04
 ID          No          No          No          Short       HiP
3.8217E-03  3.8217E-03  3.8217E-03  3.4726E-04  3.4726E-04  3.4726E-04
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SURRY TMMN WITH DH

THESE RESULTS ARE FOR THE  PESSIMISTIC      WALKTHROUGH

FREQUENCY  CFM        RCSPress  ESpr      I Spr     L Spr     CDB
8.5827E-03 NCF        HiP       No        No        Yes       Short
2.3479E-03 NCF        ImP       No        No        Yes       Short
4.6222E-04 EE1        HiP       No        No        Yes       Short
1.2644E-04 EE1        ImP       No        No        Yes       Short
3.0946E-04 LLM        HiP       No        No        No        Short
3.0139E-04 LLM        HiP       No        No        No        No
2.6457E-04 LLM        ImP       No        No        No        No
1.5925E-04 EE2        HiP       No        No        Yes       Short
1.5993E-04 EE2        HiP       No        No        Yes       No
1.5980E-04 EE2        HiP       No        No        No        Short
1.5930E-04 EE2        HiP       No        No        No        No
1.3770E-04 EE2        ImP       No        No        Yes       No
1.3732E-04 EE2        ImP       No        No        No        No
9.0450E-03 LP3        HiP       No        No        Yes       Short
3.6330E-02 LP3        HiP       No        No        No        Short
3.5525E-02 LP3        HiP       No        No        No        No
2.4743E-03 LP3        ImP       No        No        Yes       Short
9.9580E-03 LP3        ImP       No        No        No        Short
3.1198E-02 LP3        ImP       No        No        No        No
5.3556E-02 LH         HiP       No        No        Yes       Short
7.1459E-02 LH         HiP       No        No        Yes       No
3.5010E-02 LH         HiP       No        No        No        Short
3.5823E-02 LH         HiP       No        No        No        No
1.4650E-02 LH         ImP       No        No        Yes       Short
6.2756E-02 LH         ImP       No        No        Yes       No
9.5980E-03 LH         ImP       No        No        No        Short
3.1461E-02 LH         ImP       No        No        No        No
9.9995E-02 ID         HiP       No        No        Yes       Long
9.9995E-02 ID         HiP       No        No        Yes       No
9.9995E-02 ID         HiP       No        No        No        Short
9.9995E-02 ID         HiP       No        No        No        No
6.5264E-03 ID         ImP       No        No        Yes       No
6.5260E-03 ID         ImP       No        No        No        No
8.1952E-03 IS         HiP       No        No        Yes       Short
8.1952E-03 IS         HiP       No        No        Yes       No
8.1950E-03 IS         HiP       No        No        No        Short
8.1950E-03 IS         HiP       No        No        No        No
3.6072E-04 IS         ImP       No        No        Yes       Short
3.6072E-04 IS         ImP       No        No        Yes       No
3.6050E-04 IS         ImP       No        No        No        Short
3.6050E-04 IS         ImP       No        No        No        No
4.0000E-02 IA         HiP       No        No        No        Short
4.0000E-02 IA         HiP       No        No        No        No
9.9987E-03 IA         ImP       No        No        No        Short
9.9987E-03 IA         ImP       No        No        No        No

.9994025     TOTAL FREQUENCY OF BINS PRINTED

TOTAL PROBABILITY IN ALL BINS = 1.000000
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 1.8573E-05
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000019
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SURRY TMNN WITH DH

THESE ARE THE SORT  1 RESULTS FOR THE   PESSIMISTIC      WALKTHROUGH

  CFM         ESpr        I Spr       L Spr       CDB         RCSPress
  NCF         No          No          Yes         Short       HiP
                                                              8.5827E-03
  NCF         No          No          Yes         Short       ImP
1.0931E-02  1.0931E-02  1.0931E-02  1.0931E-02  1.0931E-02  2.3479E-03
  EE1         No          No          Yes         Short       HiP
                                                              4.6222E-04
  EE1         No          No          Yes         Short       ImP
5.8866E-04  5.8866E-04  5.8866E-04  5.8866E-04  5.8866E-04  1.2644E-04
  LLM         No          No          No          Short       HiP
                                                3.0946E-04  3.0946E-04
  LLM         No          No          No          No          HiP
                                                              3.0139E-04
  LLM         No          No          No          No          ImP
8.7542E-04  8.7542E-04  8.7542E-04  8.7542E-04  5.6596E-04  2.6457E-04
  EE2         No          No          Yes         Short       HiP
                                                1.5925E-04  1.5925E-04
  EE2         No          No          Yes         No          HiP
                                                              1.5993E-04
  EE2         No          No          Yes         No          ImP
                                    4.5689E-04  2.9763E-04  1.3770E-04
  EE2         No          No          No          Short       HiP
                                                1.5980E-04  1.5980E-04
  EE2         No          No          No          No          HiP
                                                              1.5980E-04
  EE2         No          No          No          No          ImP
9.1380E-04  9.1380E-04  9.1380E-04  4.5691E-04  2.9712E-04  1.3732E-04
  LP3         No          No          Yes         Short       HiP
                                                              9.0450E-03
  LP3         No          No          Yes         Short       ImP
                                    1.1519E-02  1.1519E-02  2.4743E-03
  LP3         No          No          No          Short       HiP
                                                              3.6330E-02
  LP3         No          No          No          Short       ImP
                                                4.6288E-02  9.9580E-03
  LP3         No          No          No          No          HiP
                                                              3.5525E-02
  LP3         No          No          No          No          ImP
1.2453E-01  1.2453E-01  1.2453E-01  1.1301E-01  6.6723E-02  3.1198E-02
  LM          No          No          Yes         Short       HiP
                                                              5.3556E-02
  LM          No          No          Yes         Short       ImP
                                                6.8206E-02  1.4650E-02
  LM          No          No          Yes         No          HiP
                                                              7.1459E-02
  LM          No          No          Yes         No          ImP
                                    2.0242E-01  1.3422E-01  6.2756E-02
  LM          No          No          No          Short       HiP
                                                              3.5010E-02
  LM          No          No          No          Short       ImP
                                                4.4608E-02  9.5980E-03
  LM          No          No          No          No          HiP
                                                              3.5823E-02
  LM          No          No          No          No          ImP
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3.1431E-01   3.1431E-01   3.1431E-01   1.1189E-01   6.7284E-02   3.1461E-02
 ID           No           No           Yes          Long         HiP
                                                     9.9995E-02   9.9995E-02
 ID           No           No           Yes          No           HiP
                                                                  9.9995E-02
 ID           No           No           Yes          No           ImP
                                        2.0652E-01   1.0652E-01   6.5264E-03
 ID           No           No           No           Short        HiP
                                                     9.9995E-02   9.9955E-02
 ID           No           No           No           No           HiP
                                                                  9.9995E-02
 ID           No           No           No           No           ImP
4.1303E-01   4.1303E-01   4.1303E-01   2.0652E-01   1.0652E-01   6.5260E-03
 IS           No           No           Yes          Short        HiP
                                                                  8.1952E-03
 IS           No           No           Yes          Short        ImP
                                                     8.5559E-03   3.6072E-04
 IS           No           No           Yes          No           HiP
                                                                  8.1952E-03
 IS           No           No           Yes          No           ImP
                                        1.7112E-02   8.5559E-03   3.6072E-04
 IS           No           No           No           Short        HiP
                                                                  8.1950E-03
 IS           No           No           No           Short        ImP
                                                     8.5555E-03   3.6050E-04
 IS           No           No           No           No           HiP
                                                                  8.1950E-03
 IS           No           No           No           No           ImP
3.4223E-02   3.4223E-02   3.4223E-02   1.7111E-02   8.5555E-03   3.6050E-04
 IA           No           No           No           Short        HiP
                                                                  4.0000E-02
 IA           No           No           No           Short        ImP
                                                     4.9998E-02   9.9987E-03
 IA           No           No           No           No           HiP
                                                                  4.0000E-02
 IA           No           No           No           No           ImP
9.9997E-02   9.9997E-02   9.9997E-02   9.9997E-02   4.9998E-02   9.9987E-03


******* PROCESSING COMPLETE FOR   3 WALKTHROUGHS *******
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SURRY TYYB WITH DH

THESE RESULTS ARE FOR THE  OPTIMISTIC       WALKTHROUGH

FREQUENCY  CFM        RCSPress  HSpr      I Spr     L Spr     CDB
7.2679E-01 NCF        ImP       Yes       Yes       Yes       Long
7.2679E-02 NCF        ImP       Yes       Yes       Yes       No
4.4864E-02 NCF        LoP       Yes       Yes       Yes       Short
4.0377E-02 NCF        LoP       Yes       Yes       Yes       No
9.5727E-03 EE1        ImP       Yes       Yes       Yes       Long
9.5691E-04 EE1        ImP       Yes       Yes       Yes       No
5.9079E-04 EE1        LoP       Yes       Yes       Yes       Short
5.3156E-04 EE1        LoP       Yes       Yes       Yes       No
8.9000E-03 LLM        ImP       Yes       Yes       Yes       No
4.9495E-03 LLM        LoP       Yes       Yes       Yes       No
6.4735E-02 LP2        ImP       Yes       Yes       Yes       Long
6.5632E-03 LP2        ImP       Yes       Yes       Yes       No
6.4784E-04 LP2        ImP       Yes       Part      No        Long
3.9960E-03 LP2        LoP       Yes       Yes       Yes       Short
3.6362E-03 LP2        LoP       Yes       Yes       Yes       No
8.0919E-03 LP3        ImP       Yes       Yes       Yes       Long
8.1788E-04 LP3        ImP       Yes       Yes       Yes       No
4.9938E-04 LP3        LoP       Yes       Yes       Yes       Short
4.5432E-04 LP3        LoP       Yes       Yes       Yes       No

.9996445     TOTAL FREQUENCY OF BINS PRINTED


TOTAL PROBABILITY IN ALL BINS = 1.000000
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 6.2430E-06
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000006
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 SURRY TYYB WITH DH

THESE ARE THE SORT  1 RESULTS FOR THE   OPTIMISTIC        WALKTHROUGH

  CPM          ESpr         I Spr        L Spr        CDS          RCSPress
  MCP          Yes          Yes          Yes          Long         ImP
                                                      7.2679E-01   7.2679E-01
  MCP          Yes          Yes          Yes          Short        LoP
                                                      4.4864E-02   4.4864E-02
  MCP          Yes          Yes          Yes          No           ImP
                                                                   7.2679E-02
  MCP          Yes          Yes          Yes          No           LoP
 8.8471E-01   8.8471E-01   8.8471E-01   8.8471E-01   1.1306E-01   4.0377E-02
  EE1          Yes          Yes          Yes          Long         ImP
                                                      9.5727E-03   9.5727E-03
  EE1          Yes          Yes          Yes          Short        LoP
                                                      5.9079E-04   5.9079E-04
  EE1          Yes          Yes          Yes          No           ImP
                                                                   9.5691E-04
  EE1          Yes          Yes          Yes          No           LoP
 1.1652E-02   1.1652E-02   1.1652E-02   1.1652E-02   1.4885E-03   5.3156E-04
  LLM          Yes          Yes          Yes          No           ImP
                                                                   8.9090E-03
  LLM          Yes          Yes          Yes          No           LoP
 1.3858E-02   1.3858E-02   1.3858E-02   1.3858E-02   1.3858E-02   4.9495E-03
  LP2          Yes          Yes          Yes          Long         ImP
                                                      6.4735E-02   6.4735E-02
  LP2          Yes          Yes          Yes          Short        LoP
                                                      3.9960E-03   3.9960E-03
  LP2          Yes          Yes          Yes          No           ImP
                                                                   6.5452E-03
  LP2          Yes          Yes          Yes          No           LoP
                            7.8913E-02   7.8913E-02   1.0181E-02   3.6362E-03
  LP2          Yes          Part         No           Long         ImP
 7.9560E-02   7.9560E-02   6.4784E-04   6.4784E-04   6.4784E-04   6.4784E-04
  LP3          Yes          Yes          Yes          Long         ImP
                                                      8.0919E-03   8.0919E-03
  LP3          Yes          Yes          Yes          Short        LoP
                                                      4.9938E-04   4.9938E-04
  LP3          Yes          Yes          Yes          No           ImP
                                                                   8.1788E-04
  LP3          Yes          Yes          Yes          No           LoP
 9.8635E-03   9.8635E-03   9.8635E-03   9.8635E-03   1.2722E-03   4.5432E-04
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SURRY TTYB WITH LH

THESE RESULTS ARE FOR THE  CENTRAL         WALKTHROUGH

FREQUENCY  CFM        RCSPress  ESpr        I Spr      L Spr      CDB
2.7811E-01 NCF        HiP       Yes         Yes        Yes        Long
7.4212E-02 NCF        HiP       Yes         Yes        Yes        Short
1.9573E-02 NCF        HiP       Yes         Yes        Yes        No
1.5512E-02 NCF        ImP       Yes         Yes        Yes        Long
3.7122E-02 NCF        ImP       Yes         Yes        Yes        Short
7.1866E-02 NCF        ImP       Yes         Yes        Yes        No
5.2634E-02 NCF        LoP       Yes         Yes        Yes        Short
7.1875E-02 NCF        LoP       Yes         Yes        Yes        No
8.0279E-03 EE1        HiP       Yes         Yes        Yes        Long
2.1422E-03 EE1        HiP       Yes         Yes        Yes        Short
5.6494E-04 EE1        HiP       Yes         Yes        Yes        No
4.4777E-04 EE1        ImP       Yes         Yes        Yes        Long
1.0716E-03 EE1        ImP       Yes         Yes        Yes        Short
2.0743E-03 EE1        ImP       Yes         Yes        Yes        No
1.5193E-03 EE1        LoP       Yes         Yes        Yes        Short
2.0745E-03 EE1        LoP       Yes         Yes        Yes        No
2.0183E-02 LLM        HiP       Yes         Yes        Yes        No
7.4104E-02 LLM        ImP       Yes         Yes        Yes        No
1.8246E-04 LLM        ImP       Yes         Part       No         No
7.4114E-02 LLM        LoP       Yes         Yes        Yes        No
1.8328E-04 LLM        LoP       Yes         Part       No         No
6.3974E-04 EE2        HiP       No          Yes        Yes        Long
1.7010E-04 EE2        HiP       No          Yes        Yes        Short
3.2926E-04 EE2        ImP       No          Yes        Yes        No
1.2047E-04 EE2        LoP       Yes         Yes        Yes        Short
3.2909E-04 EE2        LoP       Yes         Yes        Yes        No
3.1793E-03 LP2        HiP       Yes         Yes        Yes        Long
8.4838E-04 LP2        HiP       Yes         Yes        Yes        Short
4.4252E-04 LP2        HiP       Yes         Yes        Yes        No
3.5326E-03 LP2        HiP       Yes         Part       No         Long
9.4265E-04 LP2        HiP       Yes         Part       No         Short
4.9191E-04 LP2        HiP       Yes         Part       No         No
1.7728E-04 LP2        ImP       Yes         Yes        Yes        Long
4.2437E-04 LP2        ImP       Yes         Yes        Yes        Short
1.6264E-03 LP2        ImP       Yes         Yes        Yes        No
1.9698E-04 LP2        ImP       Yes         Part       No         Long
4.7152E-04 LP2        ImP       Yes         Part       No         Short
1.8071E-03 LP2        ImP       Yes         Part       No         No
6.0161E-04 LP2        LoP       Yes         Yes        Yes        Short
1.6264E-03 LP2        LoP       Yes         Yes        Yes        No
6.6846E-04 LP2        LoP       Yes         Part       No         Short
1.8088E-03 LP2        LoP       Yes         Part       No         No
2.8614E-02 LP3        HiP       Yes         Yes        Yes        Long
7.6354E-03 LP3        HiP       Yes         Yes        Yes        Short
3.9871E-03 LP3        HiP       Yes         Yes        Yes        No
3.1793E-02 LP3        HiP       Yes         Part       No         Long
8.4838E-03 LP3        HiP       Yes         Part       No         Short
4.4303E-03 LP3        HiP       Yes         Part       No         No
1.5950E-03 LP3        ImP       Yes         Yes        Yes        Long
3.8193E-03 LP3        ImP       Yes         Yes        Yes        Short
1.4640E-02 LP3        ImP       Yes         Yes        Yes        No
1.7733E-03 LP3        ImP       Yes         Part       No         Long
4.2437E-03 LP3        ImP       Yes         Part       No         Short
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1.6267E-02 LP3        LoP        Yes        Part       No         No
5.4154E-03 LP3        LoP        Yes        Yes        Yes        Short
1.4642E-02 LP3        LoP        Yes        Yes        Yes        No
6.0234E-03 LP3        LoP        Yes        Part       No         Short
1.6284E-02 LP3        LoP        Yes        Part       No         No
1.3393E-03 IDH        HiP        Yes        Yes        Yes        Long
1.4876E-04 IDH        HiP        Yes        Yes        Yes        No
1.4881E-04 IDH        HiP        Yes        Part       No         Long

.9993095      TOTAL FREQUENCY OF BINS PRINTED


TOTAL PROBABILITY IN ALL BINS = 1.000000
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 1.1268E-05
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000011
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SURRY TYYB WITH DH

THESE ARE THE SORT  1 RESULTS FOR THE   CENTRAL          WALKTHROUGH

  CFM         ESpr        I Spr       L Spr       CDB         RCSPress
  NCF         Yes         Yes         Yes         Long        HiP
                                                              2.7311E-01
  NCF         Yes         Yes         Yes         Long        ImP
                                                  2.9362E-01  1.5512E-02
  NCF         Yes         Yes         Yes         Short       HiP
                                                              7.4212E-02
  NCF         Yes         Yes         Yes         Short       ImP
                                                              3.7122E-02
  NCF         Yes         Yes         Yes         Short       LoP
                                                  1.6397E-01  5.2634E-02
  NCF         Yes         Yes         Yes         No          HiP
                                                              1.9573E-02
  NCF         Yes         Yes         Yes         No          ImP
                                                              7.1866E-02
  NCF         Yes         Yes         Yes         No          LoP
6.2090E-01  6.2090E-01  6.2090E-01  6.2090E-01  1.6331E-01  7.1675E-02
  EE1         Yes         Yes         Yes         Long        HiP
                                                              8.0279E-03
  EE1         Yes         Yes         Yes         Long        ImP
                                                  8.4756E-03  4.4777E-04
  EE1         Yes         Yes         Yes         Short       HiP
                                                              2.1422E-03
  EE1         Yes         Yes         Yes         Short       ImP
                                                              1.0716E-03
  EE1         Yes         Yes         Yes         Short       LoP
                                                  4.7331E-03  1.5193E-03
  EE1         Yes         Yes         Yes         No          HiP
                                                              5.6494E-04
  EE1         Yes         Yes         Yes         No          ImP
                                                              2.0743E-03
  EE1         Yes         Yes         Yes         No          LoP
1.7922E-02  1.7922E-02  1.7922E-02  1.7922E-02  4.7137E-03  2.0745E-03
  LLM         Yes         Yes         Yes         No          HiP
                                                              2.0183E-02
  LLM         Yes         Yes         Yes         No          ImP
                                                              7.4104E-02
  LLM         Yes         Yes         Yes         No          LoP
                        1.6840E-01  1.6840E-01  1.6840E-01  7.4114E-02
  LLM         Yes         Part        No          No          ImP
                                                              1.8246E-04
  LLM         Yes         Part        No          No          LoP
1.6877E-01  1.6877E-01  3.6574E-04  3.6574E-04  3.6574E-04  1.8328E-04
  EE2         Yes         Yes         Yes         Short       LoP
                                                  1.2047E-04  1.3047E-04
  EE2         Yes         Yes         Yes         No          LoP
            4.4957E-04  4.4957E-04  4.4957E-04  3.2909E-04  3.2909E-04
  EE2         No          Yes         Yes         Long        HiP
                                                  6.3974E-04  6.3974E-04
  EE2         No          Yes         Yes         Short       HiP
                                                  1.7010E-04  1.7010E-04
  EE2         No          Yes         Yes         No          ImP
1.5887E-03  1.1391E-03  1.1391E-03  1.1391E-03  3.2926E-04  3.2926E-04
  LP2         Yes         Yes         Yes         Long        HiP
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                                                                                    3.1793E-03
LP2               Yes               Yes               Yes              Long          ImP
                                                                    3.3566E-03  1.7728E-04
LP2               Yes               Yes               Yes              Short         HiP
                                                                                    8.4838E-04
LP2               Yes               Yes               Yes              Short         ImP
                                                                                    4.2437E-04
LP2               Yes               Yes               Yes              Short         LoP
                                                                    1.8744E-03  6.0161E-04
LP2               Yes               Yes               Yes              No            HiP
                                                                                    4.4252E-04
LP2               Yes               Yes               Yes              No            ImP
                                                                                    1.6264E-03
LP2               Yes               Yes               Yes              No            LoP
                                8.9262E-03   8.9262E-03   3.6953E-03  1.6264E-03
LP2               Yes               Part              No               Long          HiP
                                                                                    3.5326E-03
LP2               Yes               Part              No               Long          ImP
                                                                    3.7295E-03  1.9698E-04
LP2               Yes               Part              No               Short         HiP
                                                                                    9.4265E-04
LP2               Yes               Part              No               Short         ImP
                                                                                    4.7152E-04
LP2               Yes               Part              No               Short         LoP
                                                                    2.0826E-03  6.6846E-04
LP2               Yes               Part              No               No            HiP
                                                                                    4.9191E-04
LP2               Yes               Part              No               No            ImP
                                                                                    1.8071E-03
LP2               Yes               Part              No               No            LoP
1.8846E-02   1.8846E-02   9.9200E-03   9.9200E-03   4.1078E-03  1.8088E-03
LP3               Yes               Yes               Yes              Long          HiP
                                                                                    2.8614E-02
LP3               Yes               Yes               Yes              Long          ImP
                                                                    3.0210E-02  1.5960E-03
LP3               Yes               Yes               Yes              Short         HiP
                                                                                    7.6354E-03
LP3               Yes               Yes               Yes              Short         ImP
                                                                                    3.8193E-03
LP3               Yes               Yes               Yes              Short         LoP
                                                                    1.6870E-02  5.4154E-03
LP3               Yes               Yes               Yes              No            HiP
                                                                                    3.9871E-03
LP3               Yes               Yes               Yes              No            ImP
                                                                                    1.4640E-02
LP3               Yes               Yes               Yes              No            LoP
                                8.0348E-02   8.0348E-02   3.3269E-02  1.4642E-02
LP3               Yes               Part              No               Long          HiP
                                                                                    3.1793E-02
LP3               Yes               Part              No               Long          ImP
                                                                    3.3566E-02  1.7733E-03
LP3               Yes               Part              No               Short         HiP
                                                                                    8.4838E-03
LP3               Yes               Part              No               Short         ImP
                                                                                    4.2437E-03
LP3               Yes               Part              No               Short         LoP
                                                                    1.8751E-02  6.0234E-03
LP3               Yes               Part              No               No            HiP
                                                                                    4.4303E-03
LP3               Yes               Part              No               No            ImP
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                                                                    1.6257E-02
   LP3          Yes          Part          No           No            LoP
1.6965E-01   1.6965E-01   8.9298E-02   6.9298E-02   3.6981E-02   1.6284E-02
   IDH          Yes          Yes           Yes          Long          HiP
                                                     1.3393E-03   1.3393E-03
   IDH          Yes          Yes           Yes          No            HiP
                          1.4881E-03   1.4881E-03   1.4876E-04   1.4876E-04
   IDH          Yes          Part          No           Long          HiP
1.6369E-03   1.6369E-03   1.4881E-04   1.4881E-04   1.4881E-04   1.4881E-04
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SURRY TTYB WITH DH

THESE RESULTS ARE FOR THE  PESSIMISTIC      WALKTHROUGH

FREQUENCY  CFM         RCSPress  ESpr      I Spr     L Spr     CDB
9.4566E-04 NCF         HiP       Yes       Yes       Yes       Long
3.9141E-03 NCF         HiP       Yes       Yes       Yes       Short
2.7573E-04 NCF         HiP       Yes       Yes       Yes       No
6.2040E-04 NCF         ImP       Yes       Yes       Yes       Short
2.1079E-04 EE1         HiP       Yes       Yes       Yes       Short
2.6174E-03 LLM         HiP       Yes       Yes       Yes       No
7.0163E-04 LLM         ImP       Yes       Yes       Yes       No
1.7916E-04 EE2         HiP       No        Yes       Yes       Short
1.8001E-04 EE2         HiP       No        Yes       Yes       No
1.7988E-04 EE2         HiP       No        No        No        Short
1.7989E-04 EE2         HiP       No        No        No        No
9.9659E-04 LP3         HiP       Yes       Yes       Yes       Long
4.1249E-03 LP3         HiP       Yes       Yes       Yes       Short
2.9084E-03 LP3         HiP       Yes       Yes       Yes       No
7.8940E-03 LP3         HiP       Yes       Part      No        Long
1.0507E-02 LP3         HiP       Yes       Part      No        Short
1.8401E-02 LP3         HiP       Yes       Part      No        No
6.5381E-04 LP3         ImP       Yes       Yes       Yes       Short
7.7970E-04 LP3         ImP       Yes       Yes       Yes       No
1.5594E-03 LP3         ImP       Yes       Part      No        Short
4.1373E-03 LP3         ImP       Yes       Part      No        No
5.9009E-03 LH          HiP       Yes       Yes       Yes       Long
2.2573E-03 LH          HiP       Yes       Yes       Yes       Short
1.2584E-02 LH          HiP       Yes       Yes       Yes       No
2.5177E-04 LH          ImP       Yes       Yes       Yes       Short
2.5779E-03 LH          ImP       Yes       Yes       Yes       No
1.0105E-01 IDH         HiP       Yes       Yes       Yes       Long
1.0105E-01 IDH         HiP       Yes       Yes       Yes       No
1.0105E-01 IDH         HiP       Yes       Part      No        Long
1.0105E-01 IDH         HiP       Yes       Part      No        No
2.2306E-02 IDH         ImP       Yes       Yes       Yes       No
2.2306E-02 IDH         ImP       Yes       Part      No        No
3.3335E-03 ID          HiP       Yes       Yes       Yes       Long
3.3335E-03 ID          HiP       Yes       Yes       Yes       No
3.3335E-03 ID          HiP       Yes       Part      No        Long
3.3335E-03 ID          HiP       Yes       Part      No        No
2.2395E-04 ID          HiP       No        Yes       Yes       Long
2.2395E-04 ID          HiP       No        Yes       Yes       No
2.2391E-04 ID          HiP       No        No        No        Short
2.2391E-04 ID          HiP       No        No        No        No
7.9271E-02 IHS         HiP       Yes       Yes       Yes       Short
7.9271E-02 IHS         HiP       Yes       Yes       Yes       No
7.9271E-02 IHS         HiP       Yes       Part      No        Short
7.9271E-02 IHS         HiP       Yes       Part      No        No
8.4198E-03 IHS         ImP       Yes       Yes       Yes       Short
8.4198E-03 IHS         ImP       Yes       Yes       Yes       No
8.4198E-03 IHS         ImP       Yes       Part      No        Short
8.4198E-03 IHS         ImP       Yes       Part      No        No
4.4910E-02 IA          HiP       Yes       No        No        Short
4.4910E-02 IA          HiP       Yes       No        No        No
4.9900E-03 IA          ImP       Yes       No        No        Short
4.9900E-03 IA          ImP       Yes       No        No        No
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.9991320     TOTAL FREQUENCY OF BINS PRINTED

TOTAL PROBABILITY IN ALL BINS = 1.000000
TOTAL PROBABILITY LOST DUE TO TERMINATION OF BRANCHES 5.6321E-06
TOTAL PROBABILITY FOR THIS WALKTHROUGH = 1.000006
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SURRY TTYB WITH DH

THESE ARE THE SORT  1 RESULTS FOR THE   PESSIMISTIC      WALKTHROUGH

 CFM         ESpr        I Spr       L Spr       CDB         RCSPress
 MCF         Yes         Yes         Yes         Long        HiP
                                                9.4566E-04  9.4566E-04
 MCF         Yes         Yes         Yes         Short       HiP
                                                            3.9141E-03
 MCF         Yes         Yes         Yes         Short       ImP
                                                4.5344E-03  6.2040E-04
 MCF         Yes         Yes         Yes         No          HiP
5.7558E-03  5.7558E-03  5.7558E-03  5.7558E-03  2.7573E-04  2.7573E-04
 EH1         Yes         Yes         Yes         Short       HiP
2.1079E-04  2.1079E-04  2.1079E-04  2.1079E-04  2.1079E-04  2.1079E-04
 LLM         Yes         Yes         Yes         No          HiP
                                                            2.6174E-03
 LLM         Yes         Yes         Yes         No          ImP
3.3191E-03  3.3191E-03  3.3191E-03  3.3191E-03  3.3191E-03  7.0163E-04
 EH2         No          Yes         Yes         Short       HiP
                                                1.7916E-04  1.7916E-04
 EH2         No          Yes         Yes         No          HiP
                        3.5917E-04  3.5917E-04  1.8001E-04  1.8001E-04
 EH2         No          No          No          Short       HiP
                                                1.7988E-04  1.7988E-04
 EH2         No          No          No          No          HiP
7.1892E-04  7.1892E-04  3.5975E-04  3.5975E-04  1.7988E-04  1.7988E-04
 LP3         Yes         Yes         Yes         Long        HiP
                                                9.9659E-04  9.9659E-04
 LP3         Yes         Yes         Yes         Short       HiP
                                                            4.1248E-03
 LP3         Yes         Yes         Yes         Short       ImP
                                                4.[illegible]786E-03  6.5381E-04
 LP3         Yes         Yes         Yes         No          HiP
                                                            2.9084E-03
 LP3         Yes         Yes         Yes         No          ImP
                        9.4633E-03  9.4633E-03  3.6881E-03  7.7970E-04
 LP3         Yes         Part        No          Long        HiP
                                                7.8940E-03  7.8940E-03
 LP3         Yes         Part        No          Short       HiP
                                                            1.0507E-02
 LP3         Yes         Part        No          Short       ImP
                                                1.2066E-02  1.5594E-03
 LP3         Yes         Part        No          No          HiP
                                                            1.8401E-02
 LP3         Yes         Part        No          No          ImP
5.1962E-02  5.1962E-02  4.2499E-02  4.2499E-02  2.2538E-02  4.1373E-03
 LH          Yes         Yes         Yes         Long        HiP
                                                5.9009E-03  5.9009E-03
 LH          Yes         Yes         Yes         Short       HiP
                                                            2.2573E-03
 LH          Yes         Yes         Yes         Short       ImP
                                                2.5091E-03  2.5177E-04
 LH          Yes         Yes         Yes         No          HiP
                                                            1.2584E-02
 LH          Yes         Yes         Yes         No          ImP
2.3572E-02  2.3572E-02  2.3572E-02  2.3572E-02  1.5162E-02  2.5779E-03
 IDH         Yes         Yes         Yes         Long        HiP
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                                                                        1.0105E-01        1.0105E-01
  IDH               Yes               Yes               Yes               No                HiP
                                                                                          1.0105E-01
  IDH               Yes               Yes               Yes               No                ImP
                                    2.2440E-01        2.2440E-01        1.2335E-01        2.2306E-02
  IDH               Yes               Part              No                Long              HiP
                                                                        1.0105E-01        1.0105E-01
  IDH               Yes               Part              No                No                HiP
                                                                                          1.0105E-01
  IDH               Yes               Part              No                No                ImP
4.4880E-01        4.4880E-01        2.2440E-01        2.2440E-01        1.2335E-02        2.2306E-02
  ID                Yes               Yes               Yes               Long              HiP
                                                                        3.3335E-03        3.3335E-03
  ID                Yes               Yes               Yes               No                HiP
                                    6.6669E-03        6.6669E-03        3.3335E-03        3.3335E-03
  ID                Yes               Part              No                Long              HiP
                                                                        3.3335E-03        3.3335E-03
  ID                Yes               Part              No                No                HiP
                  1.3334E-02        6.6669E-03        6.6669E-03        3.3335E-03        3.3335E-03
  ID                No                Yes               Yes               Long              HiP
                                                                        2.2395E-04        2.2395E-04
  ID                No                Yes               Yes               No                HiP
                                    4.4790E-04        4.4790E-04        2.2395E-04        2.2395E-04
  ID                No                No                No                Short             HiP
                                                                        2.2391E-04        2.2391E-04
  ID                No                No                No                No                HiP
1.4230E-02        8.9572E-04        4.4782E-04        4.4782E-04        2.2391E-04        2.2391E-04
  IHS               Yes               Yes               Yes               Short             HiP
                                                                                          7.9271E-02
  IHS               Yes               Yes               Yes               Short             ImP
                                                                        8.7691E-02        8.4198E-03
  IHS               Yes               Yes               Yes               No                HiP
                                                                                          7.9271E-02
  IHS               Yes               Yes               Yes               No                ImP
                                    1.7538E-01        1.7538E-01        8.7691E-02        8.4198E-03
  IHS               Yes               Part              No                Short             HiP
                                                                                          7.9271E-02
  IHS               Yes               Part              No                Short             ImP
                                                                        8.7691E-02        8.4198E-03
  IHS               Yes               Part              No                No                HiP
                                                                                          7.9271E-02
  IHS               Yes               Part              No                No                ImP
3.5076E-01        3.5076E-01        1.7538E-01        1.7538E-01        8.7691E-02        8.4198E-03
  IA                Yes               No                No                Short             HiP
                                                                                          4.4910E-02
  IA                Yes               No                No                Short             ImP
                                                                        4.9900E-02        4.9900E-03
  IA                Yes               No                No                No                HiP
                                                                                          4.4910E-02
  IA                Yes               No                No                No                ImP
9.9800E-02        9.9800E-02        9.9800E-02        9.9800E-02        4.9900E-02        4.9900E-03
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Abbey, Frank
U.K. Atomic Energy Authority
Wigshaw Lane, Culcheth
Warrington, Chesira
United Kingdom, WA3 4NE

Aftergood, Steven
Committee to Bridge the Gap
1637 Butler Avenue, #203
Los Angeles, CA 90025

Amos, C. N.
Technadyne, Inc.
300 Virginia SE
Albuquerque, NM 87108

Apostolakis, George
University of California, Los Angeles
Boelter Hall, Room 5532
Los Angeles, CA 90024

Ashkar, James W.
Boston Edison Company
800 Boylston Street
Boston, MA 02199

Ashton, Donald H.
Bechtel Power Corporation
15740 Shady Grove Road
Gaithersburg, MD 20877

Averett, Mark
Florida Power Corporation
P.O. Box 14042
St. Petersburg, FL 33733

Aycock, Michael B.
TERA Corporation
7101 Wisconsin Avenue
Bethesda, MD 20814

Bagley, Raymond O.
Northeast Utilities
P.O. Box 270
Hartford, CT 06101

Bagues, J.
Consejo de Seguridad Nucleare
Sorangela de la Cruz 3
Madrid 38046
Spain

Bairiot, H.
Belgonucleaire S A
Rue de Champ de Mars 25
B-1050 Brussels
Belgium

Balkovetz, Fred J.
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415

Baranowsky, Patrick
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Bari, Robert A.
Brookhaven National Laboratories
Building 130
Upton, NY 11973

Barrett, Richard
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, DC 20555

Baskin, Kenneth S.
S. California Edison Company
P.O. Box 800
Rosemead, CA 91770

Bastl, Werner
Gesellschaft Fur Reaktorsicherheit
Forschungsgelande
8046 Garching
Federal Republic of Germany

Baybutt, Paul
Battelle Columbus Division
505 King Avenue
Columbus, OH 43201

Beckley, Bruce B.
Public Service Company
P.O. Box 330
Manchester, NH 03105

Bender, Myer
Querytech, Inc.
403 Cedar Bluff Road
Knoxville, TN 37923

Bertucio, R. C.
Energy Incorporated
1851 So. Central Place, Suite 201
Kent, WA 98031

Bieniarz, Peter
Risk Management Association
2309 Dietz Farm Road, NW
Albuquerque, NM 87107

Birkhofer, Adolf
Gesellschaft Fur Reaktorsicherheit
Forschungsgelande
8046 Garching
Federal Republic of Germany

Blackburn, James
Illinois Dept. of Nuclear Safety
1035 Outer Park Drive
Springfield, IL 62704

Bley, Dennis C.
Pickard, Lowe & Garrick, Inc.
2260 University Drive
Newport Beach, CA 92660

Blond, Roger M.
Science Applications Int. Corp.
1710 Goodridge Drive
McLean, VA 22102

Bourne, A. John
U.K. Atomic Energy Authority
Wigshaw Lane, Culcheth
Warrington, Chesire
United Kingdom, WA3 4NE

Boyd, G. J.
Safety & Reliability Optimization
  Services
9724 Kingston Pike
Knoxville, TN 37922

Brinkmann, K. J.
Netherlands Energy Res. Fdtn.
P.O. Box 1
1755ZG Petten NH
Netherlands

Buchholz, R. H.
Nutech
6835 Via Del Oro
San Jose, CA 95119

Buckman, Fred
Delian Corporation
296 Duff Road
Monroeville, PA 15146

Budnitz, Robert J.
Future Resources Associates
734 Alameda
Berkeley, CA 94707

Buhl, A. R.
International Technology Corp.
575 Oak Ridge Turnpike
Oak Ridge, TN 37830

Burdick, Gary R.
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Canady, Kenneth S.
Duke Power Company
422 S. Church Street
Charlotte, NC 28217

Carlsson, Lennart
Swedish Nuclear Power Inspectorate
Box 27106
Stockholm, Sweden 08-635560
Sweden

Carnino, Annick
Electricite de France
32 Rue de Monceau 8EME
Paris, France F5008
France

Cathey, N. G.
Idaho National Engineering Lab.
P. O Box 1625
Idaho Falls, ID 83415

Catton, Ivan
22436 Galilee Street
Woodland Hills, CA 91364

Chakraborty, S.
Radiation Protection Section
Div. De La Securite Des Inst. Nuc.
5303 Wurenlingen, Switzerland
Switzerland

Chang, Sen-I
Institute of Nuclear Energy Research
P.O. Box 3
Lungtan, 325 Taiwan

Christie, Robert F.
Tennessee Valley Authority
400 W. Summit Hill Avenue, W10D1
90 Knoxville, TN 37902

Coffman, Frank
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, DC 20555

Conradi, Larry L.
Energy Incorporated
1851 South Central Place, Suite 201
Kent, WA 98031

Cooper, Peter
U.K. Atomic Energy Authority
Wigshaw Lane, Culcheth
Warrington, Chesire
United Kingdom, WA3 4NE

Corradini, Michael
University of Wisconsin
1500 Johnson Drive
Madison, WI 53706

Cullingford, Michael
IAEA
P.O. Box 200
A-1400 Vienna, Austria

Cummings, Garth
Lawrence Livermore Laboratory
L-91, Box 808
Livermore, CA 94526

Cunningham, Mark A.
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Curry, James J.
7135 Salem Park Circle
Mechanicsburg, PA 17055

Cybulskis, Peter
Battelle Columbus Division
505 King Avenue
Columbus, OH 43201

Davis, Peter R.
Intermountain Technologies, Inc.
P.O. Box 1604
Idaho Falls, ID 83401

DeCarlos, Jose
Sor Angela De la Cruz, No. 3, Planta 8
Madrid 28016, Spain

Deem, Richard
New York Power Authority
123 Main Street
White Plains, NY 10601

Denning, Richard S.
Battelle Columbus Division
505 King Avenue
Columbus, OH 43201

DiSalvo, Raymond
Battelle Columbus Division
505 King Avenue
Columbus, OH 43201

El-Bassioni, Adel A.
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, DC 20555

Elliott, J. Mark
International Energy Associates, Ltd.
600 New Hampshire Ave, NW, Suite 600
Washington, DC 20037

Energy Issues Rep.
Sierra Club
1228 North Street, #31
Sacramento, CA 95814

Ernst, Malcolm L.
U.S. Nuclear Regulatory Commission
101 Marietta Street, Suite 3100
Atlanta, GA 30323

Executive Director
Natural Resources Defense Council
122 East 42nd Street
New York, NY 10168

Fehrenback, P.
Atomic Energy Canada, Ltd.
Chalk River
Ontario, Canada

176

Fiege, A.
Kernforschungszentrum
Postfach 3640
7500 Karlsruhe
Federal Republic of Germany

Flanagan, George F.
Oak Ridge National Laboratories
P.O. Box Y
Oak Ridge, TN 37831

Fontana, Mario
International Technology Corp.
575 Oak Ridge Turnpike
Oak Ridge, TN 37830

Fray, Ray R.
Pacific Gas and Electric Co.
215 Market Street, Room 206
San Francisco, CA 94106

Fulford, James
NUS Corporation
910 Clopper Road
Gaithersburg, MD 20878

Fussell, J. B.
JBF Associates, Inc.
1630 Downtown West Boulevard
Knoxville, TN 37919

Gallucci, Raymond H. V.
Battelle Pacific Northwest Labs.
P.O. Box 999
Richland, WA 99352

Garrick, John
Pickard, Lowe & Garrick, Inc.
2260 University Drive
Newport Beach, CA 92660

Gaunt, John
British Embassy
3100 Massachusetts Avenue, NW
Washington, DC 20008

Gieseke, J.
Battelle Columbus Division
505 King Avenue
Columbus, OH 43201

Glynn, James C.
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Hammar, L.
Statens Karnkraftinspektion
P.O. Box 27106
S-10252 Stockholm, Sweden

Hayns, M. R.
U.K. Atomic Energy Authority
Wigshaw Lane, Culcheth
Warrington, Chesire
United Kingdom WA3 4NE

Henry, Robert E.
Fauske and Associates, Inc.
16W070 West 83rd Street
Burr Ridge, IL 60521

Hirsch, Daniel
University of California
A. Stevenson Prog. on Nuclear Policy
Santa Cruz, CA 95064

Hodge, Steven
Oak Ridge National Laboratories
P.O. Box Y
Oak Ridge, TN 37831

Houghton, Thomas C.
KMC, Inc.
1747 Pennsylvania Avenue, NW
Washington, DC 20006

Houston, Dean
U.S. Nuclear Regulatory Commission
Advisory Comm. on Reactor Safeguards
Washington, DC 20555

Hsia, Der Yu
Taiwan Atomic Energy Council
67, Lane 144, Keelung Rd., Sec. 4
Taipei, Taiwan

Jaquith, R. E.
Combustion Engineering, Inc.
1000 Prospect Hill Road
M/C 9490-2405
Windsor, CT 06095

Johannson, Kjell
Studsvik Energiteknik AB
S-611 82, Nykoping, Sweden

Johnson, D. H.
Pickard, Lowe & Garrick, Inc.
2260 University Drive
Newport Beach, CA 92660

Joksimovich, Vojin
NUS Corporation
16885 W. Bernardo Drive
San Diego, CA 92127

Jun, H. R.
Korea Adv. Energy Research Inst.
P.O. Box 7, Daeduk Danju
Chungnam 300-31, Korea

Kafka, Peter
Gesellschaft Fur Reaktorsicherheit
Forschungsgelande 8046 Garching
Federal Republic of Germany

Kahatib-Rahbar, M.
Brookhaven National Laboratory
Associated Universities, Inc.
Upton, NY 11973

Kaiser, Geoffrey D.
NUS Corporation
910 Clopper Road
Gaithersburg, MD 20878

Kastenberg, W.
UCLA
5532 Boelter Hall
Los Angeles, CA 90024

Kato, W.
Brookhaven National Laboratory
Associated Universities, Inc.
Upton, NY 11973

Kerr, William
University of Michigan, North Campus
Department of Nuclear Engineering
Ann Arbor, MI 48109

Klopp, George
Commonwealth Edison Company
P.O. Box 767, Room 35W
Chicago, IL 60690

Koberlein, Klaus
Gesellschaft Fur Reaktorsicherheit
Forschungsgelande 8046 Garching
Federal Republic of Germany

Kohn, E.
Atomic Energy Canada Ltd.
Candu Operations, Mississauga
Ontario, Canada

Kouts, Herbert J. C.
Brookhaven National Laboratories
Building 179C
Upton, L.I. NY 11973

Kress, Thomas
Oak Ridge National Laboratories
P.O. Box Y
Oak Ridge, TN 37831

Lanore, Jeanne-Marie
CEA B.P. No. 6
92660 Fonenay-Au-Roses, France

Lee, John C.
University of Michigan, North Campus,
Dept. of Nuclear Engineering
Ann Arbor, MI 48109

Lewis, Harold W.
University of California
Physics Department
Santa Barbara, CA 93106

Librarian
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Lin, Eng
Taiwan Power Company
242, Roosevelt Rd., Sec. 3
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Longworth, J. P.
Central Electric Gen'Ting Brd.
Berkeley Gloucester
GL13 9PB United Kingdom

Luckas, William J.
Brookhaven National Laboratories
Building 130
Upton, L.I., NY 11973

Ludewig, Hans
Brookhaven National Laboratories
Building 130
Upton, L.I., NY 11973

MacDonald, P.
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415

Malinauskas, A. P.
Oak Ridge National Laboratories
P.O. Box Y
Oak Ridge, TN 37831

Mancini, Giuseppe
Commission European Comm.
CEC-JRC Eraton
Ispra Varese, Italy

McGowan, Alan
Scientists Institute for Public Info.
355 Lexington Avenue
New York, NY 10017

Meyer, Ralph
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Mitchell, Joselyn
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Murphy, Joseph A.
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Niemczyk, Sue
1545 18th St. NW, #112
Washington, DC 20036

O'Donnell, Edward P.
Ebasco Services, Inc.
2 World Trade Center, 89th Floor
New York, NY 10048

Okrent, David
University of California, Los Angeles
Boelter Hall, Room 5532
Los Angeles, CA 90024

Parkinson, William
Delian Corporation
1340 Saratoga-Sunnyvale Road
Suite 206
San Jose, CA 95129

Petrangeli, G.
ENEA Nucl. Energ. ALT Disp
Via V Brancati 48
00144 Roma, Italy

Pollard, Robert D.
Union of Concerned Scientists
1616 P Street, NW, Suite 310
Washington, DC 20036

Potter, R.
UK Atomic Energy Authority
Winfrith Dorchester Dorset
DT2 8DH United Kingdom

Pratt, William T.
Brookhaven National Laboratories
Building 130
Upton, NY 11973

Pyatt, David
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Rasmussen, Ingvard
Riso National Laboratory
Postbox 49 DK-4000
Roskilde, Denmark

Rasmussen, Norman C.
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

Richardson, Dennis
Westinghouse Electric Corporation
P. O. Box 355
Pittsburg, PA 15230

Ritzman, Robert
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304

Ross, Denwood F.
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Rowsome, Frank
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, DC 20555

Siegal, John
Atomic Industrial Forum
7101 Wisconsin Avenue
Bethesda, MD 20814

Siess, Chester P.
Advisory Comm. on Reactor Safeguards
805 Hamilton Drive
Champaign, IL 61820

Silberberg, Melvin
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555

Soda, K.
Japan Atomic Energy Res. Inst.
Tokai-Mura Naka-Gun
IBARAKI-KEN 319-11, Japan

Soffer, Leonard
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, DC 20555

Speis, Themis P.
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, DC 20555

Stadie, Klaus B.
OECD-NEA, 38 Bld. Suchet
75016 Paris, France

Stiede, Wayne L.
Commonwealth Edison Company
P.O. Box 767
Chicago, IL 60690

Taylor, John
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

Taylor, Merrill A.
U.S. Nuclear Regulatory Commission
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Theofanous, T. G.
University of California, S.B.
Dept. of Chemical and Nuclear Eng.
Santa Barbara, CA 93106

Thompson, Gordon
Inst. for Resource & Security
Studies
27 Elsworth Avenue
Cambridge, MA 02139

Tong, Long Sun
9733 Lookout Place
Gaithersburg, MD 20879

Torri, A. F.
Pickard, Lowe & Garrick, Inc.
191 Calle Magdalena, Suite 290
Encinitas, CA 92024

Tung, Chao-Chin
Atomic Energy Council
67 Lane 144, Sec 4, Keelung Rd.
Taipei, Taiwan

Wall, Ian B.
Electric Power Research Institute
P.O. Box 10412
Palo Alto, CA 94303

Ward, David
Savannah River Laboratories
Building 773-A, A-219
Aiken, SC 29808

Warman, Edward
Stone & Webster Engineering Corp.
P.O. Box 2325
Boston, MA 02107

Weber, Norman
Sargent & Lundy Co.
55 E. Monroe Street
Chicago, IL 60603

Webster, Lois
American Nuclear Society
555 N. Kensington Avenue
La Grange Park, IL 60525

184

Wood, Paul
Delian Corporation
296 Duff Road
Monroeville, PA 15146

Wreathall, John
Battelle Columbus Division
505 King Avenue
Columbus, OH 43201

Wyrick, Roger
Inst. for Nuclear Power Operations
1100 Circle 75 Parkway, Suite 1500
Atlanta, GA 30339

Young, Jonathan
Energy, Inc.
1851 South Central Place
Suite 201
Kent, WA 98031

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Sandia National Laboratories
Albuquerque, NM 87185

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13 ABSTRACT (200 words or less)

A study has been performed as part of the Severe Accident Risk Reduction Program (SARRP) to investigate the response of a particular pressurized water reactor with a subatmospheric containment (Surry Unit 1) to postulated severe accidents. A detailed containment event tree for the Surry plant has been devised to describe the various possible accident pathways that can lead to radioactive releases from containment. Data and analyses from a large number of NRC and industry-sponsored programs have been reviewed and used as a basis for quantifying the event tree, i.e., determining the likelihood of each pathway for a variety of accident sequence initiators. A generalized containment event tree code, called EVNTRE, has been developed to facilitate the quantification. The uncertainty in the results has been examined by performing the quantification three times, using a different set of input each time to represent the variation of opinion in the reactor safety community. In the so-called "central" estimate, the likelihood of early containment failure (occurring before or at the time of reactor vessel breach) was found to be very low for most accident sequence initiators. However, uncertainties surrounding the issues of direct containment pressure capacity could lead to much higher early failure likelihoods. This work supports NRC's assessment of severe accident risks to be published in NUREG-1150.

14 DOCUMENT ANALYSIS - a KEYWORDS/DESCRIPTORS

b IDENTIFIERS/OPEN-ENDED TERMS

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containment failure
containment release
EVNTRE computer code

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